TRAVEL - TIME ANOMALIES AT LASA

7 JULY 1967

REPORT No. LL-6

Prepared for

LINCOLN LABORATORIES
MASSACHUSETTS INSTITUTE of TECHNOLOGY

EARTH SCIENCES
A TELEDYNE COMPANY

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FOREWORD

The work documented in this report is part of a study of the travel-time and amplitude anomalies observed at the Large Aperture Seismic Array (LASA) in Montana. This report supersedes Report No. LL-1, "Travel- Time Anomalies at LASA" in that additional data and data quality control have been used to obtain the results presented in this report.

This report was written by D. E. Frankowski and F. A. Klappenberger. Assistance in the collection of data was provided by A. L. Kurtz, V. R. McLamore, R. D. Mierley, P. A. Santiago, H. N. Johnson, F. J. Whited, and D. A. Beschen. Dr. E. F. Chiburis served as a consultant. The project director was Dr. P. W. Broome.

ABSTRACT

World-wide average travel-time curves are inadequate to permit optimum phasing of teleseismic signals. Phase alignment corrections in the form of station relative travel-time anomalies of LASA, based on approximately 570 events, are presented.

Accepted for the Air Force
Franklin C. Hudson
Chief, Lincoln Laboratory Office

1. INTRODUCTION

World-wide average travel-time curves are known to be inadequate to permit optimum phasing of teleseismic signals. This is not a serious problem for events of large recorded earth motion since it is possible to adjust a preliminary alignment using measurements taken from the signal itself. For events where the signal is obscured by noise, however, these corrections to the preliminary alignment must be known a priori. This report presents time-shift corrections in the form of station relative travel-time anomalies for the Montana LASA. These corrections are based upon travel-time observations at the center seismometers of all 21 subarrays for approximately 570 events (see Figure 1).

2. PROCEDURE

2.1 Data Processing

Figure 2a illustrates the manner in which the initial P-wave from an event travels from the source to LASA. Ideally, the wave front passes across LASA, as shown in Figure 2b. Because of travel-time anomalies, however, this idealized situation is not observed.

Figure 2c shows a typical record of an event as seen on the 16mm Develocorder film. Two such films record the earth motion for all 21 center seismometers. Necessary corrections to the JB travel-time tables are established by comparing these arrival times with the predicted times. This establishes corrections for a particular event region.[1]

Data recorded for one event is shown in Figure 3a. This data is keypunched as indicated in Figure 3b. Then, using the definition of the travel-time anomaly

$$Ot_I = (T_I - P_I) - (T_O - P_O)$$

1. Chiburis and Dean, "Teleseismic Signal Alignment at the Tonto Forest Extended Array," SDL Report No. 125, 15 October 1965.

where T and P are observed and predicted travel-times at station I and reference station O, respectively, the anomalies are computed using AO-10 as a reference as shown in Figure 3c.

In all cases, the USC&GS source data and JB travel-time curves are used as a standard. Any bias errors in USC&GS data will thus be reflected as correction errors. The P-phase arrival times at each center are read from the 16mm film at a magnification of 20 on a projected image view screen. The timing point of each arrival is defined as: "the earliest motion within the first quarter cycle which can be read most accurately and consistently on all channels."

Since some channels may have poor traces, the readings are all qualified by a quality grade as follows:

Quality Grade 1 = a perfect trace

Grade 2 = a trace that is easily read

Grade 3 = a trace on which the signal is seen but is not distinct.

Grade 4 = a trace on which the signal cannot be seen.

The object of this process is to obtain corrections which can be defined as a mathematically simple function of distance and azimuth from LASA. To achieve this, events were grouped into cells by distance and azimuth relative to LASA and the average relative travel-time anomaly of all events in a cell were then calculated for each subarray. The travel-time anomaly was assumed constant within each cell at this point in the analysis. The standard deviation and number of events included in the cell population were also calculated (a sample of this result is shown in Figure 4). The complete anomaly data is shown in Figures 6 through 25.

One would expect large standard deviations in a cell population if either the anomaly were not nearly constant within a cell, or if abnormal errors existed in the data. (The results in this report were obtained by using all except Grade 4 data).

2.2 Error Detection

The desired result has been to obtain average travel-time anomalies to within 0.1 second or better. Using the data from Figures 6 to 25, a statistical study was undertaken so that outliers could be defined and re-examined. The error model used in this study was based on the classical notion of experimental error due to inherent observation variations. The error model proposed in this case is the result of two main causes. The first component of the model is due to the error in reading the film traces. The second is due to epicenter location errors. We assume these errors to be normally distributed* and independent of one another. Thus, the total reading error Z is assumed to be such that

$$Z \in N\left[\mu_R + \mu_L, \ (\sigma^2_R + \sigma^2_L)^{\frac{1}{2}}\right]$$

where μ_R and μ_L, σ^2_R and σ^2_L are the means and variances of the reading and location errors respectively.

The mean μ_R due to reading is assumed to be zero. Then, since all readings are referred to the USC&GS locations, we further assume that μ_L is zero. The effect of this is to correct LASA so that it agrees with USC&GS.

An estimate S^2, of σ^2, the variance of the entire population, is computed in each cell. By pooling these estimates one obtains an improved estimate which is very good due to the large number of cells. The procedure is as follows: The estimates in each cell are entered on a histogram, Figure 5, as a function of the number of events in that cell.

A pooled estimate of the population variance is then

$$\bar{S}^2 = \left[\sum_{N=2}^{\infty} \sum_{j=0}^{\infty} f_{N,j} \ S^2_j\right] \div \left[\sum_{N=2}^{\infty} \sum_{j=0}^{\infty} f_{N,j}\right] ,$$

*The statistical methods used are not especially sensitive to the accuracy of this assumption.

where $f_{N,j}$ is the number of estimates in the class interval indexed by j and with N events in each of the cells. The value of S^2_j is equal to the center value of the variance in the class of interval j.

The estimate for σ^2 is sufficiently good so that we may compute $100(1-\alpha)\%$ confidence intervals for S_N^2 and S_N.

We set $\sigma^2 = \bar{S}^2$,

and $\sigma = (\bar{S}^2)^{\frac{1}{2}}$.

The confidence intervals are then defined from the relation,

$$\frac{\sigma^2}{f}\chi^2_{(\alpha/2),f} < S_N^2 < \frac{\sigma^2}{f}\chi^2_{(1-\alpha/2),f}$$

or

$$\left[\frac{\chi^2_{(\alpha/2),f}}{f}\right]^{\frac{1}{2}} \sigma < S_N < \left[\frac{\chi^2_{(1-\alpha/2),f}}{f}\right]^{\frac{1}{2}} \sigma,$$

where f = number of degrees of freedom and $\chi^2_{(\alpha/2),f}$ and $\chi^2_{(1-\alpha/2),f}$ are found in tables.

After these confidence limits are established, we then proceeded to question all outliers. Since σ is estimated from the population and it is the population which are questioning, this is a bootstrap operation. If, for N events, a S^2 was computed which fell within the 95% limits, the S^2 was accepted as a reasonable estimate for σ^2. If, however, the computed S^2 fell outside the confidence intervals, the estimate was questioned and the time anomalies involved in computing the estimate were re-examined for errors beyond the expected film reading and epicenter location errors. In this way, about 1% of the readings

were found to be in error. These errors have been removed from the data in Figures 5 through 26.

2.3 Computer Programs

Two programs were used in this study. One computed the anomalies using the film readings and the USC&GS event data. The second computed average anomalies in specified range and azimuth cells given the anomaly data. The second, in addition, computed estimates of the error variance in each cell. Program write-ups are included as Appendices A and B.

3. CONCLUSIONS AND FUTURE PLANS

Travel-time anomaly data for geographic regions of high seismicity can be taken from Figures 6 through 25 or can be supplied in IBM card form by region or on an event-by-event basis. This data may contain some errors. We are continuing to check the data for obvious blunders. Results at all times where there are few events must be considered as tentative since the only check we have on USC&GS errors is use of repeated events.

As more events are added, it becomes easier to eliminate both reading and basic data errors. We will continue to investigate those cases where the data in a cell exhibits high variability and where no obvious error has been found. Since the mean travel-time anomaly varies from cell to cell, it is not unreasonable to expect that one subdivision of a cell may exhibit a mean anomaly clearly dissimilar to that of another portion of that same cell.

ILLUSTRATIONS

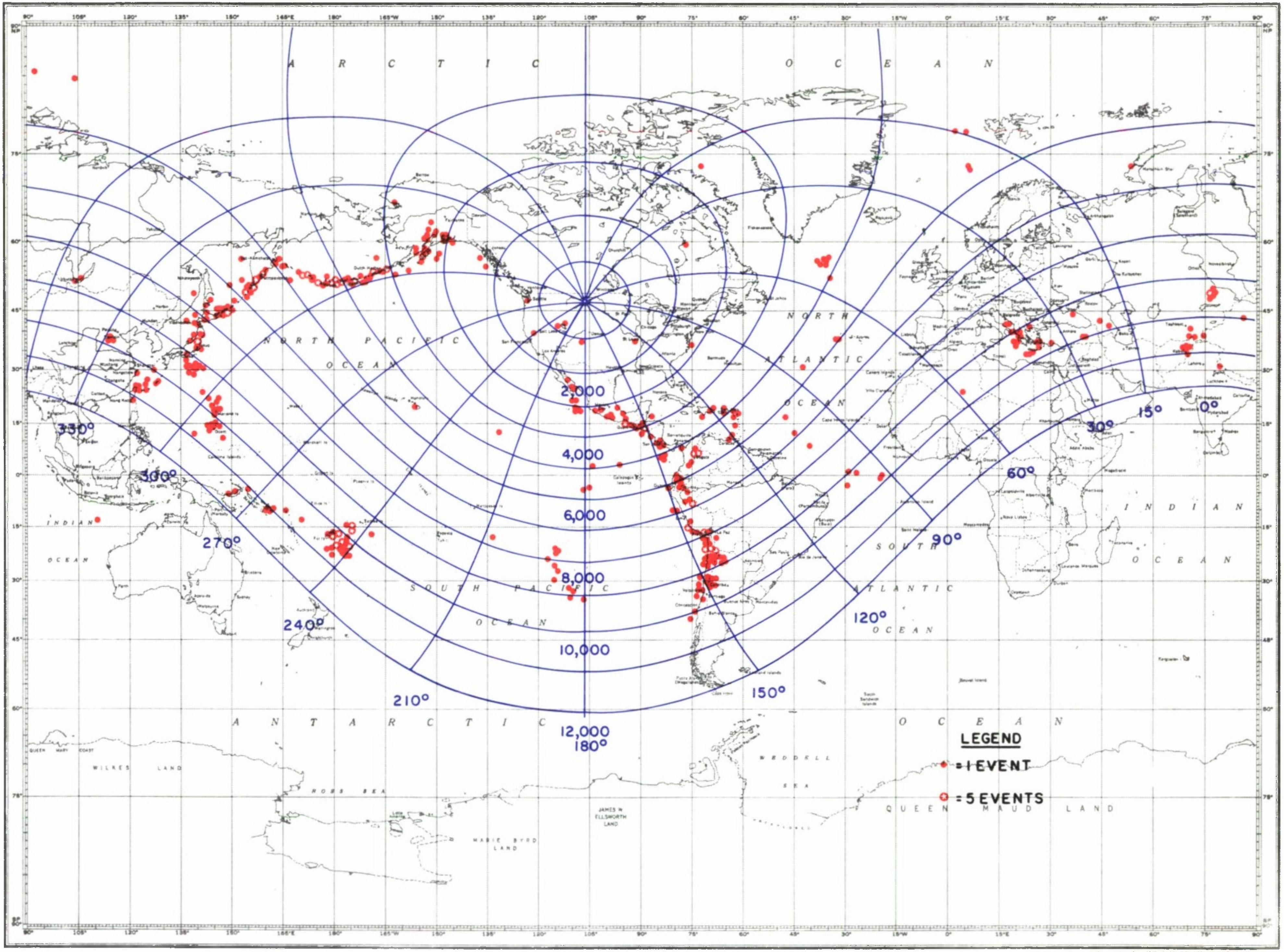


Figure 1. Event location chart

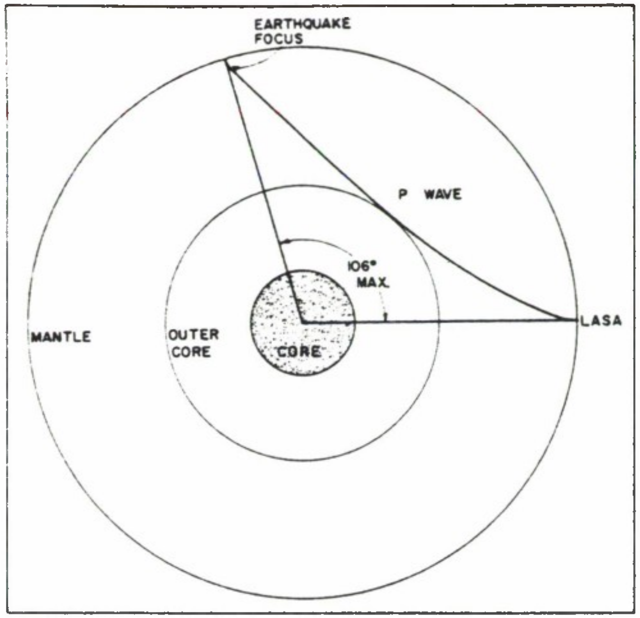


Figure 2a. Travel path from source to LASA

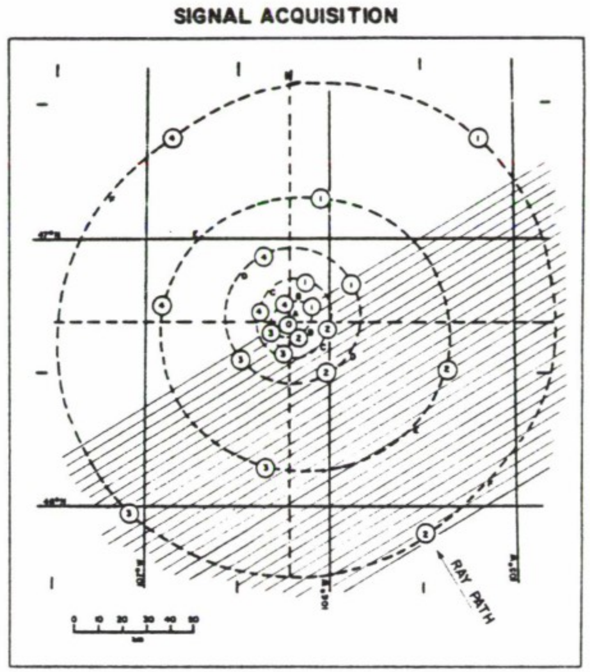
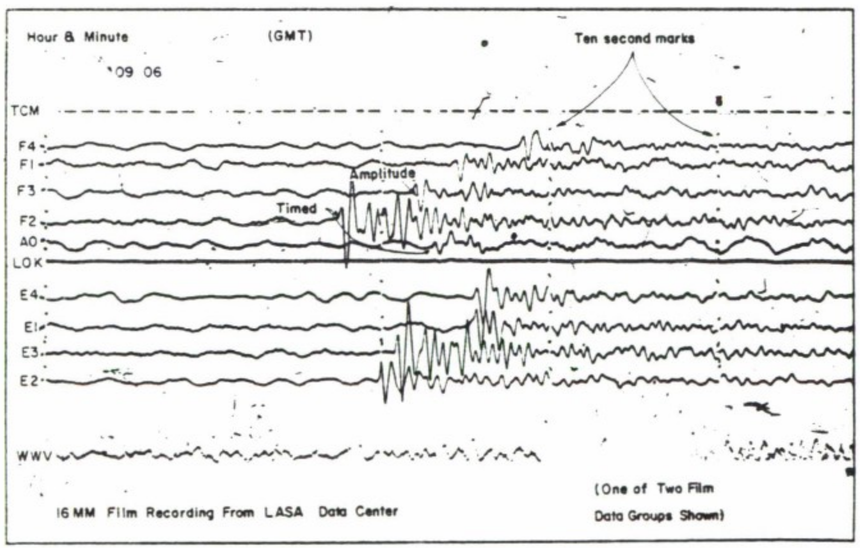


Figure 2b. Simulated wave passage across LASA



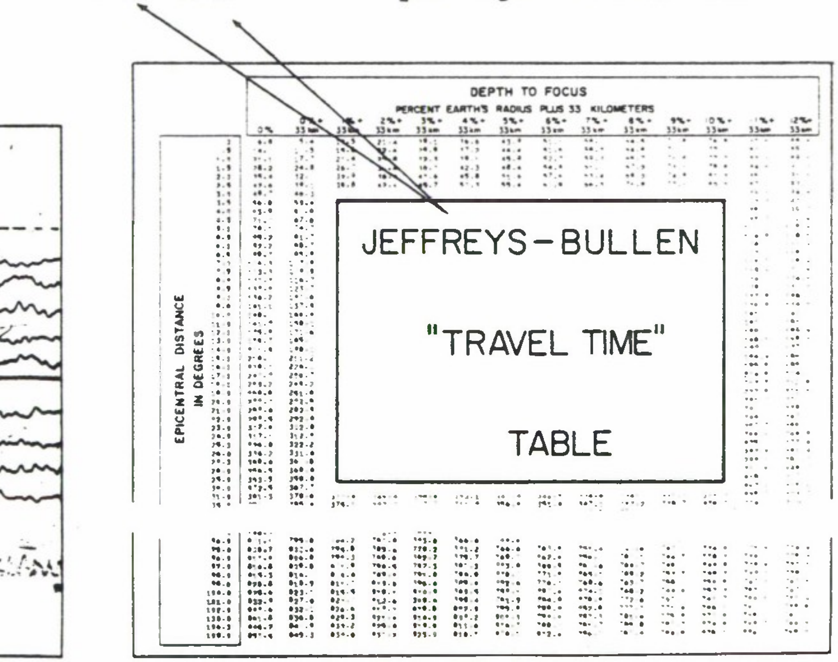


Figure 2c. Typical recording showing event arrival

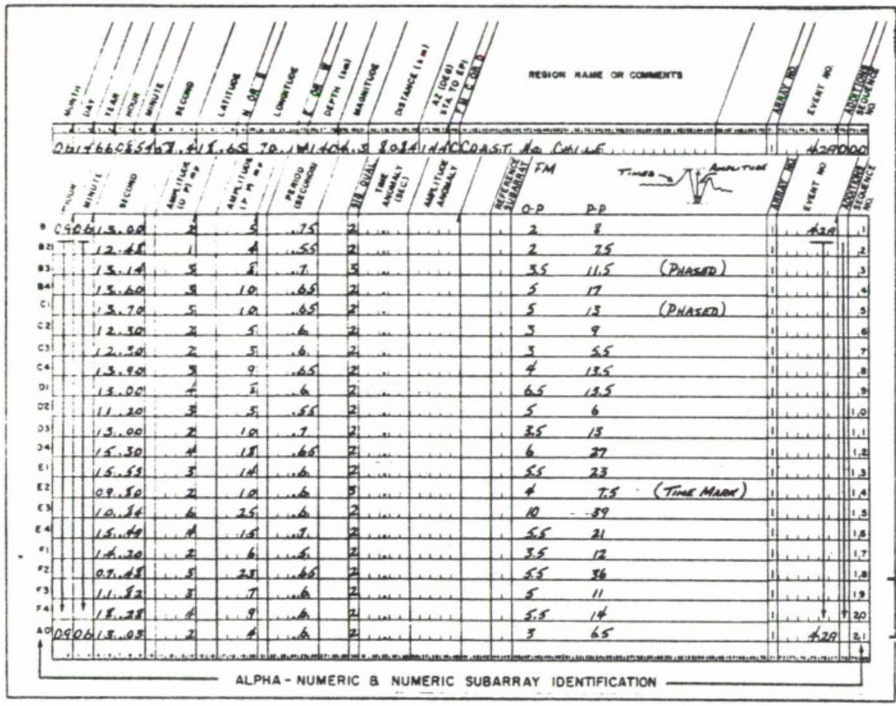
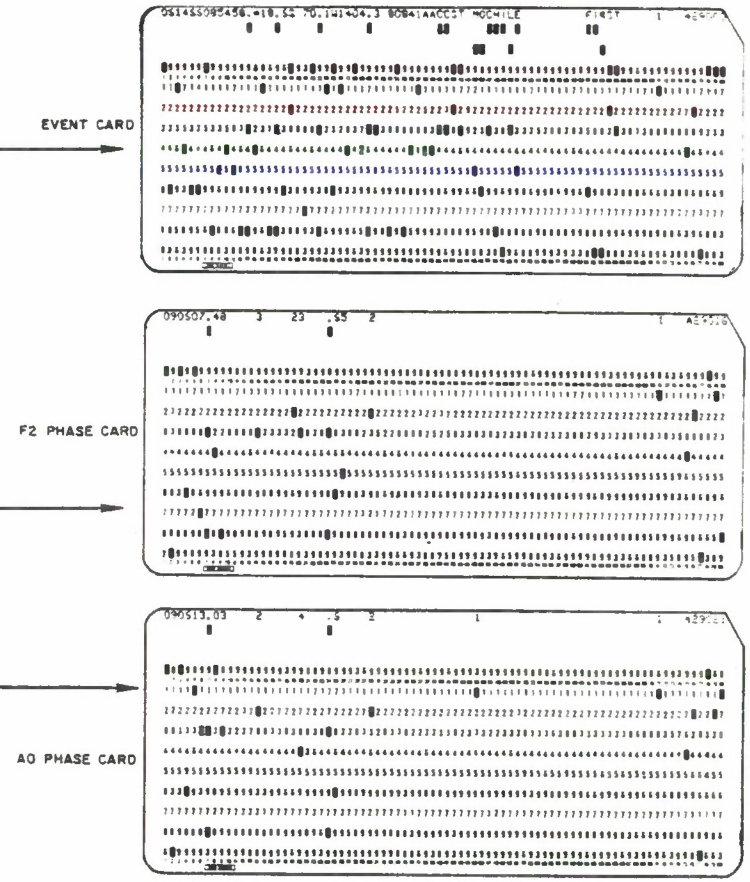


Figure 3a. Analyst's observations



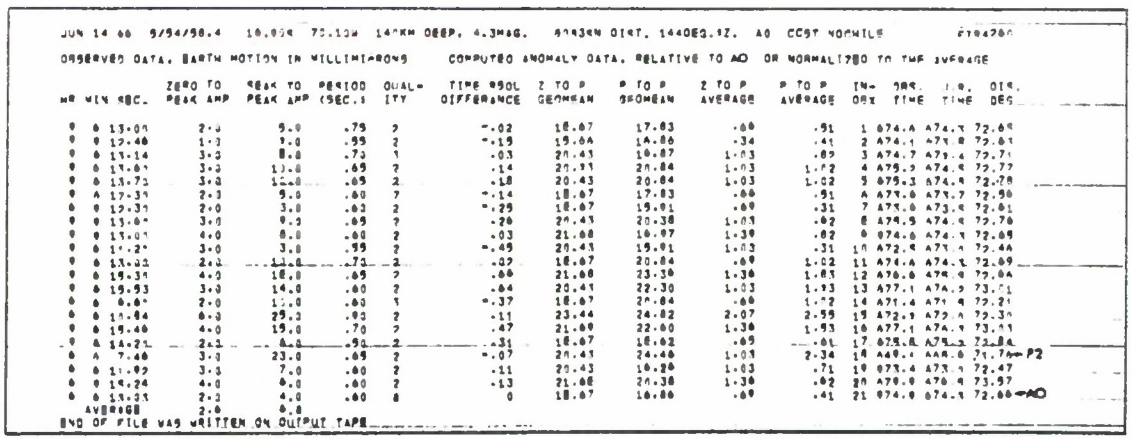


Figure 3c. Computer output listing computed anomalies for one event

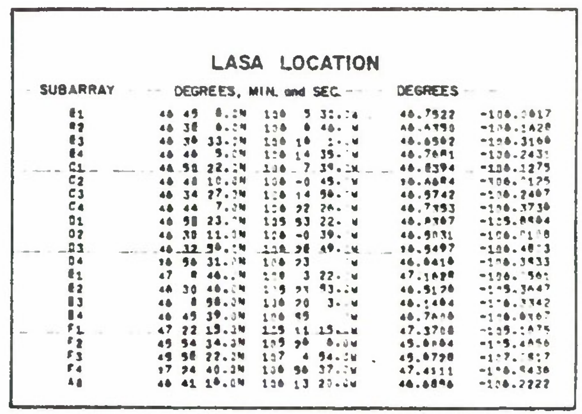


Figure 3b. Observed data in keypunched form

TIME ANOMALY DISPLAY

SUBARRAY F2

CENTER DISTANCE

CENTER AZIMUTHS	3000	3500	4000	4500	5000	5500	6000	6500	7000	7500	8000	8500	9000	9500	10000	10500	11000	
	0	0	0	0	0	0	0	0	0	0	0	0	0	-.85	-.85	-.62	-.66	MEAN
15	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	.01	0	STANDARD DEVIATION
	0	0	0	0	0	0	0	0	0	0	0	0	0	1	1	2	1	NUMBER OF EVENTS USED
	0	0	0	0	-.67	0	0	0	0	0	0	0	-.70	-.42	-.77	0	0	
45	0	0	0	0	0	0	0	0	0	0	0	0	.10	0	.07	0	0	
	0	0	0	0	1	0	0	0	0	0	0	0	3	1	4	0	0	
	0	0	0	0	0	0	-.70	0	0	0	0	0	0	0	0	0	0	
75	0	0	0	0	0	0	.01	0	0	0	0	0	0	0	0	0	0	
	0	0	0	0	0	0	2	0	0	0	0	0	0	0	0	0	0	
	0	0	0	0	-.53	-.32	0	0	0	0	0	0	-.57	0	-.45	0	0	
105	0	0	0	0	0	.27	0	0	0	0	0	0	0	0	0	0	0	
	0	0	0	0	1	3	0	0	0	0	0	0	1	0	1	0	0	
	0	0	-.01	.25	.18	-.11	.13	-.02	-.01	-.19	-.12	-.18	-.16	-.08	0	0	0	
135	0	0	.14	0	.09	.14	.16	0	0	0	.08	.04	.07	0	0	0	0	
	0	0	3	1	5	6	2	1	1	1	5	8	5	1	0	0	0	
	-.03	.06	-.05	0	.04	0	0	0	0	0	0	0	.07	-.21	-.13	0	0	
165	0	.11	.07	0	0	0	0	0	0	0	0	0	0	.12	0	0	0	
	1	5	3	0	1	0	0	0	0	0	0	0	1	3	1	0	0	
	-.17	0	0	0	0	0	0	0	0	0	-.27	0	-.23	0	0	0	0	
195	.17	0	0	0	0	0	0	0	0	0	0	0	.26	0	0	0	0	
	3	0	0	0	0	0	0	0	0	0	1	0	3	0	0	0	0	
	0	0	0	0	0	0	0	0	0	0	0	0	0	0	-.67	-.60	0	
225	0	0	0	0	0	0	0	0	0	0	0	0	0	0	.01	.06	0	
	0	0	0	0	0	0	0	0	0	0	0	0	0	0	2	2	0	
	0	0	0	0	0	0	0	0	0	0	0	0	0	-.73	-.67	-.64	0	
255	0	0	0	0	0	0	0	0	0	0	0	0	0	.13	.07	.08	0	
	0	0	0	0	0	0	0	0	0	0	0	0	0	6	13	8	0	
	0	0	0	0	0	0	0	0	0	0	0	0	0	-.49	-.43	-.42	0	
285	0	0	0	0	0	0	0	0	0	0	0	0	0	.06	.18	0	0	
	0	0	0	0	0	0	0	0	0	0	0	0	0	2	2	1	0	
	-.46	-.32	-.53	-.55	-.59	-.57	-.40	-.36	-.51	-.34	-.26	-.31	-.35	-.34	-.16	-.29	-.27	
315	0	.07	.13	.09	.07	.07	0	.08	.07	.11	.08	.09	0	.03	.17	.09	.04	
	1	8	4	7	11	10	1	7	6	5	4	8	1	2	3	5	2	
	0	0	0	0	0	0	0	0	0	0	0	0	0	-.52	0	0	0	
345	0	0	0	0	0	0	0	0	0	0	0	0	0	.07	0	0	0	
	0	0	0	0	0	0	0	0	0	0	0	0	0	2	0	0	0	

SAMPLE

Figure 4. Sample output

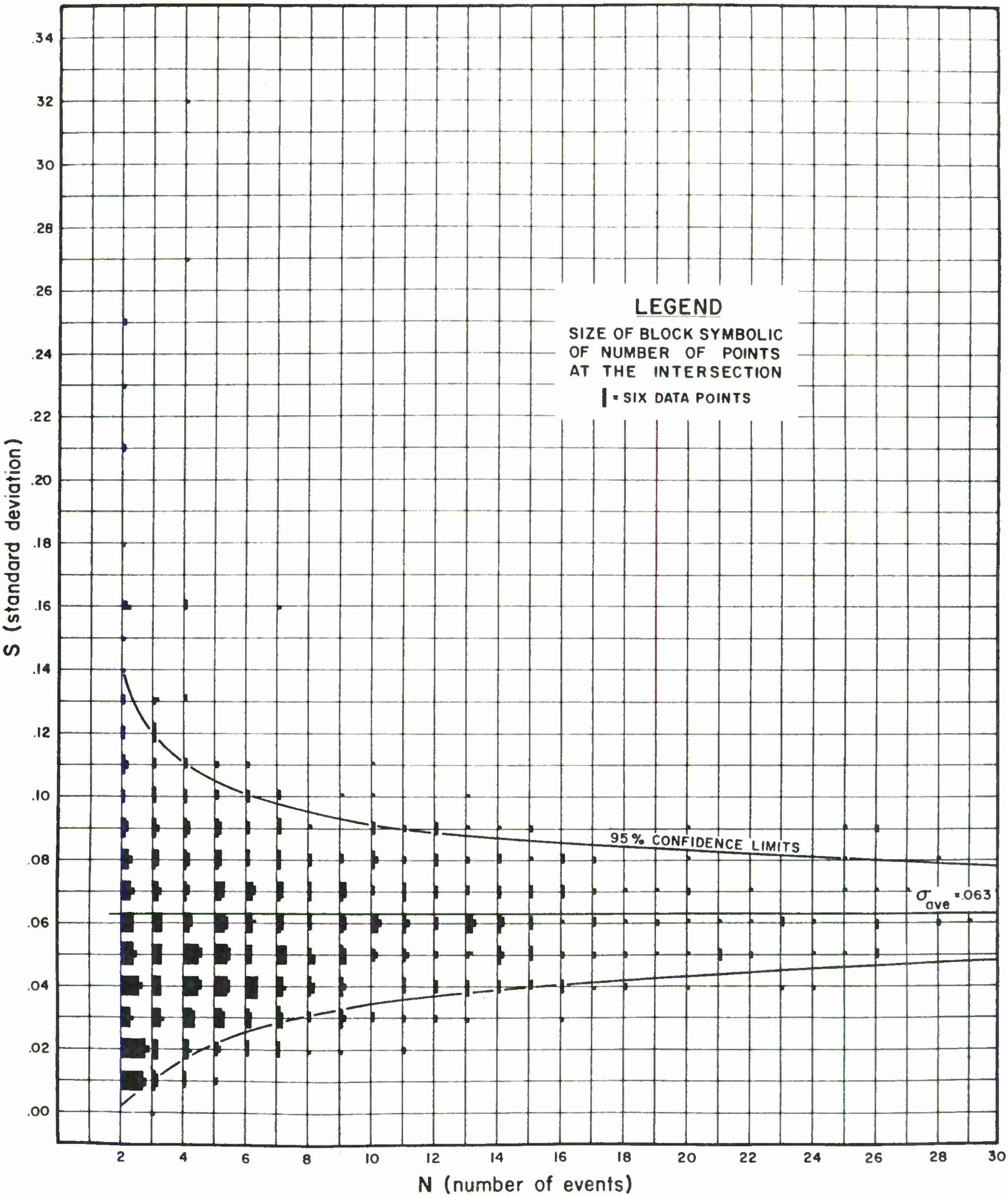


Figure 5. Distribution of standard deviation computed from N events

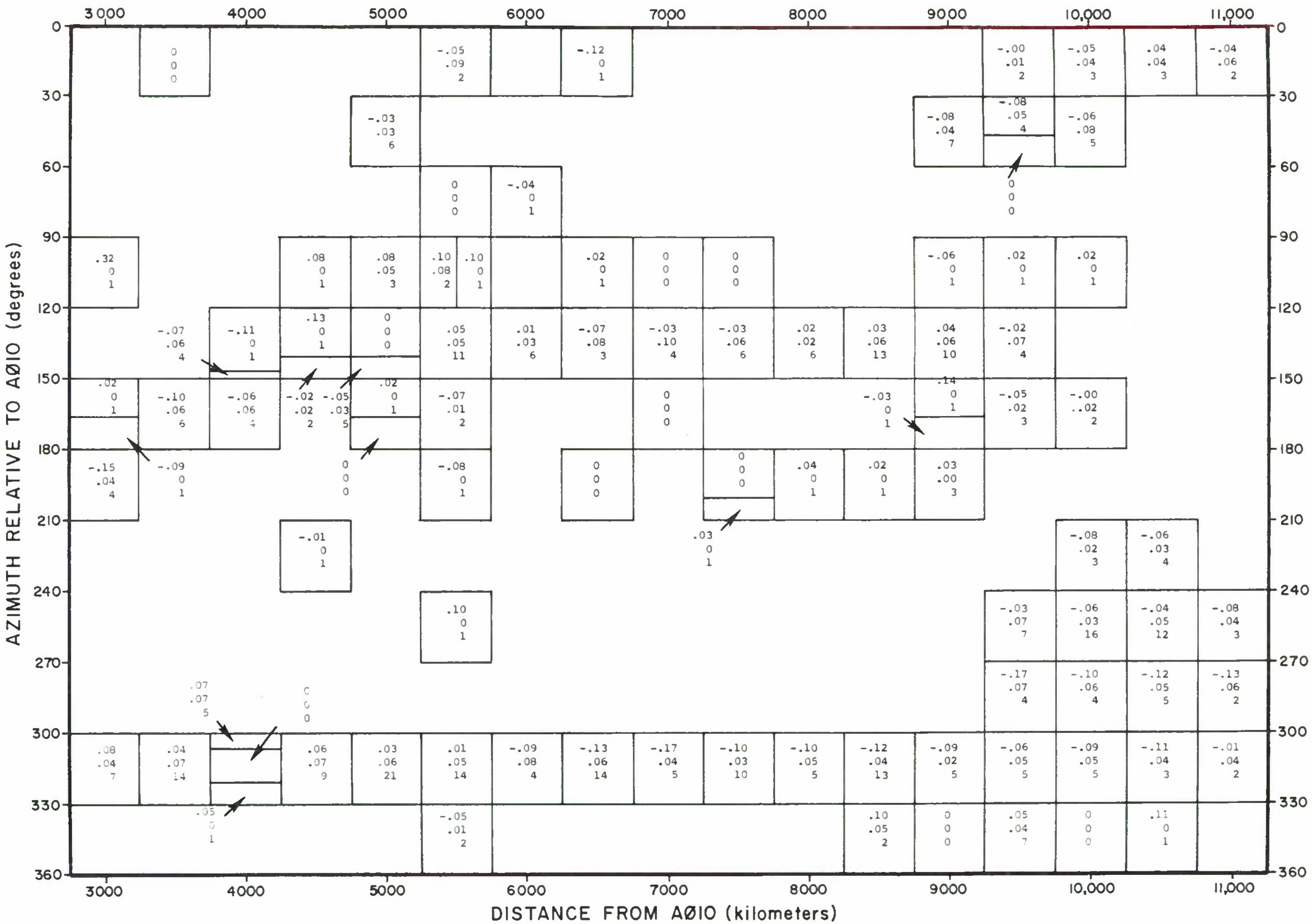


Figure 6. Subarray B1

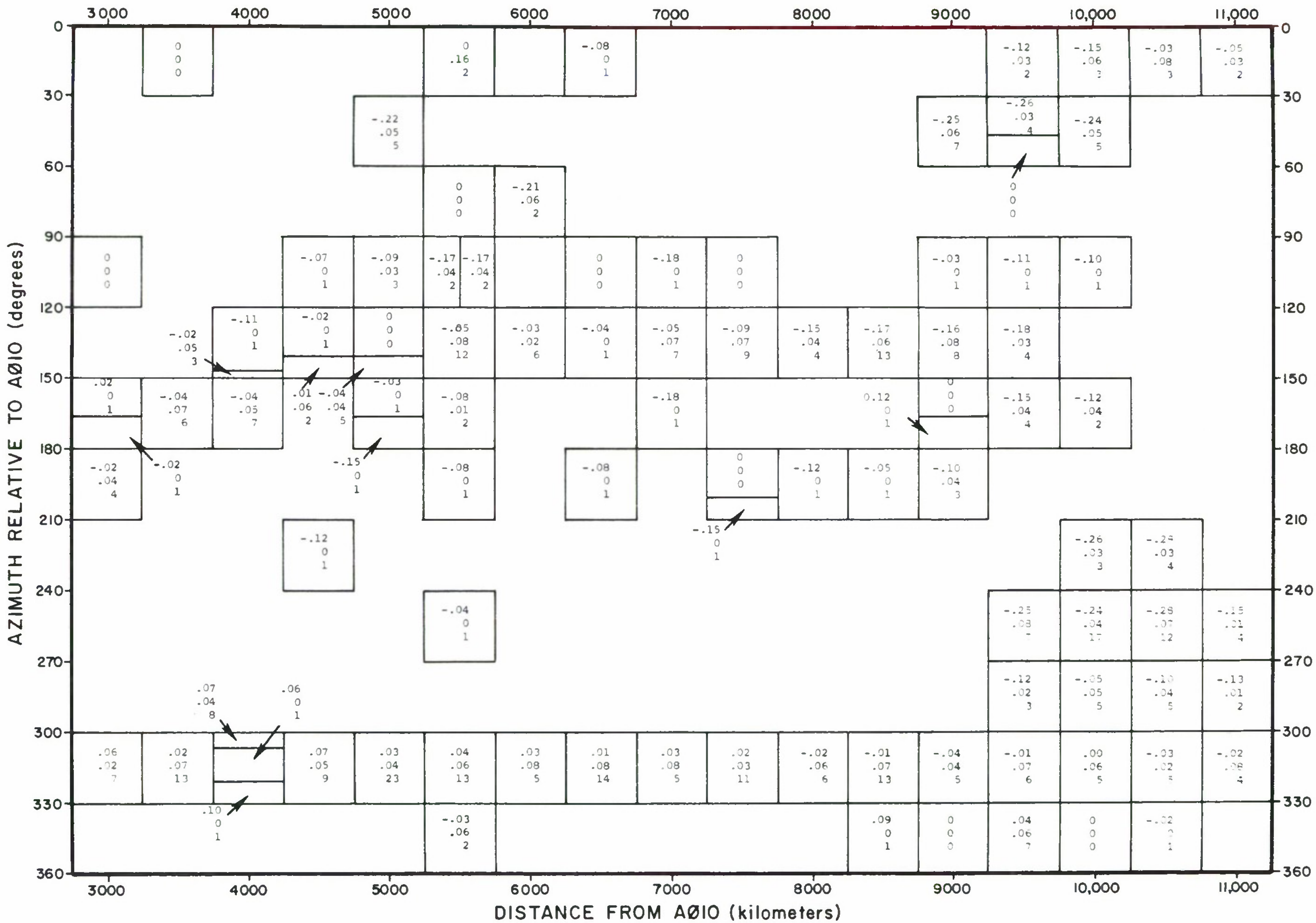


Figure 7. Subarray B2

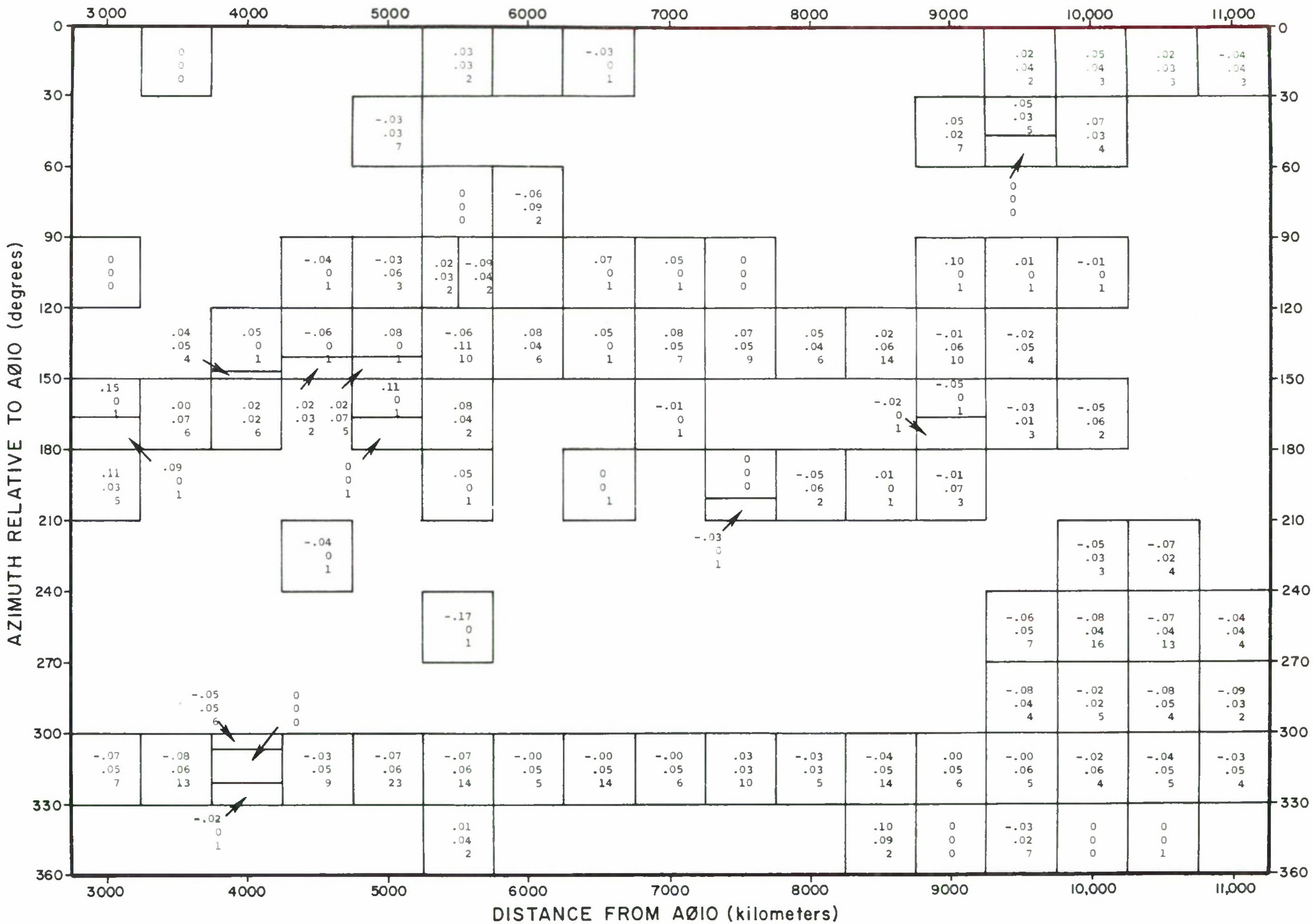


Figure 8. Subarray B3

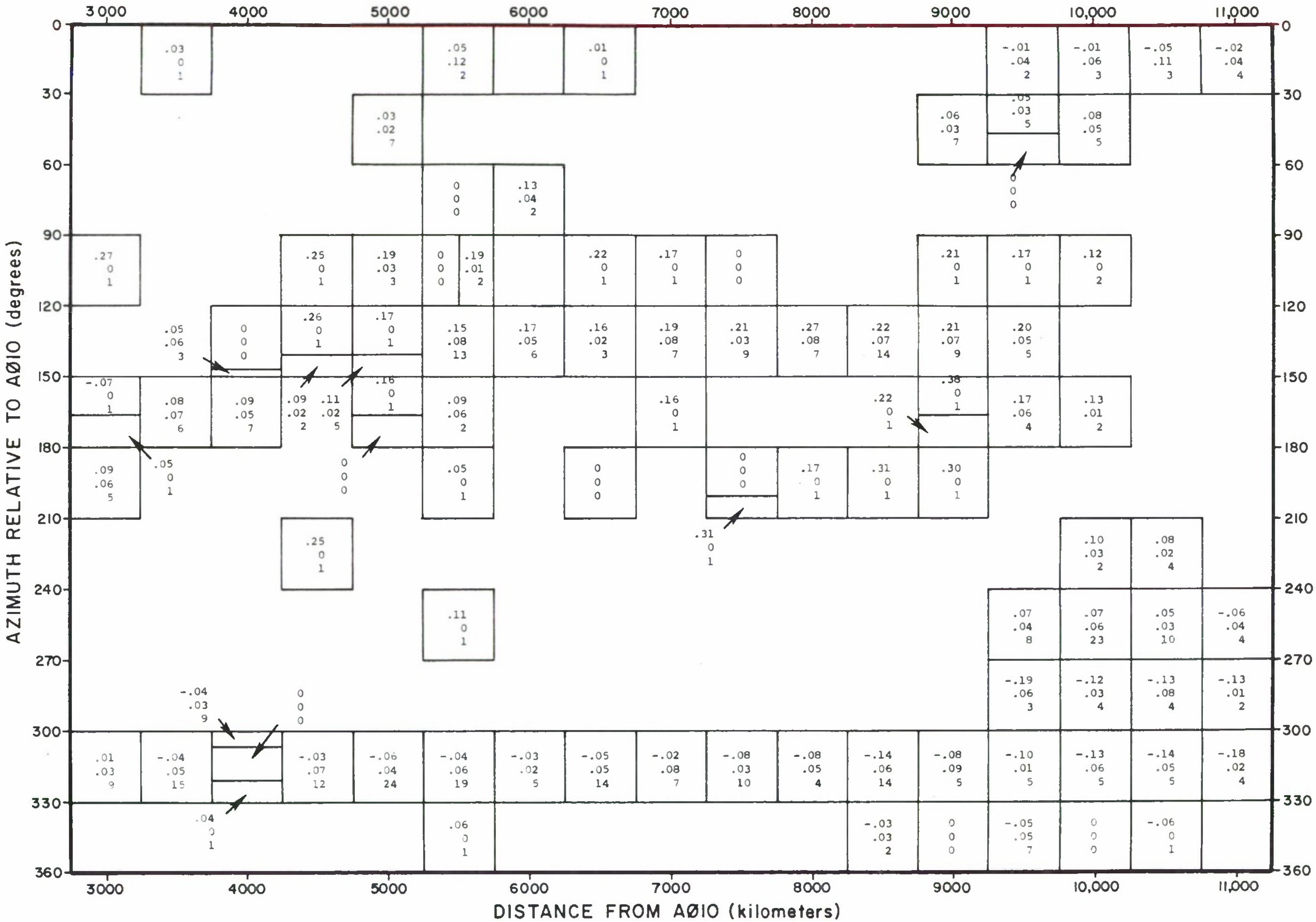


Figure 9. Subarray B4

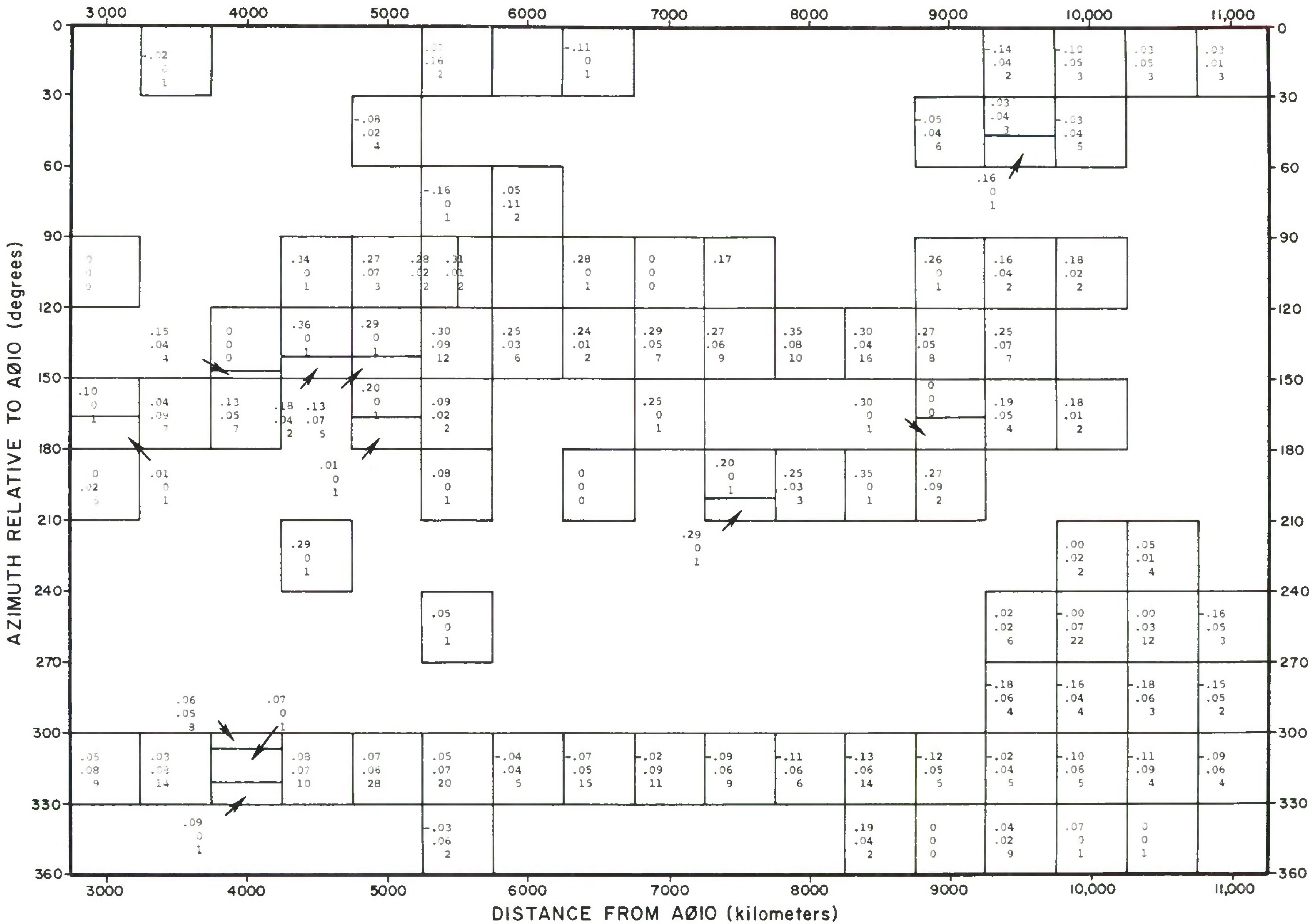


Figure 10. Subarray C1

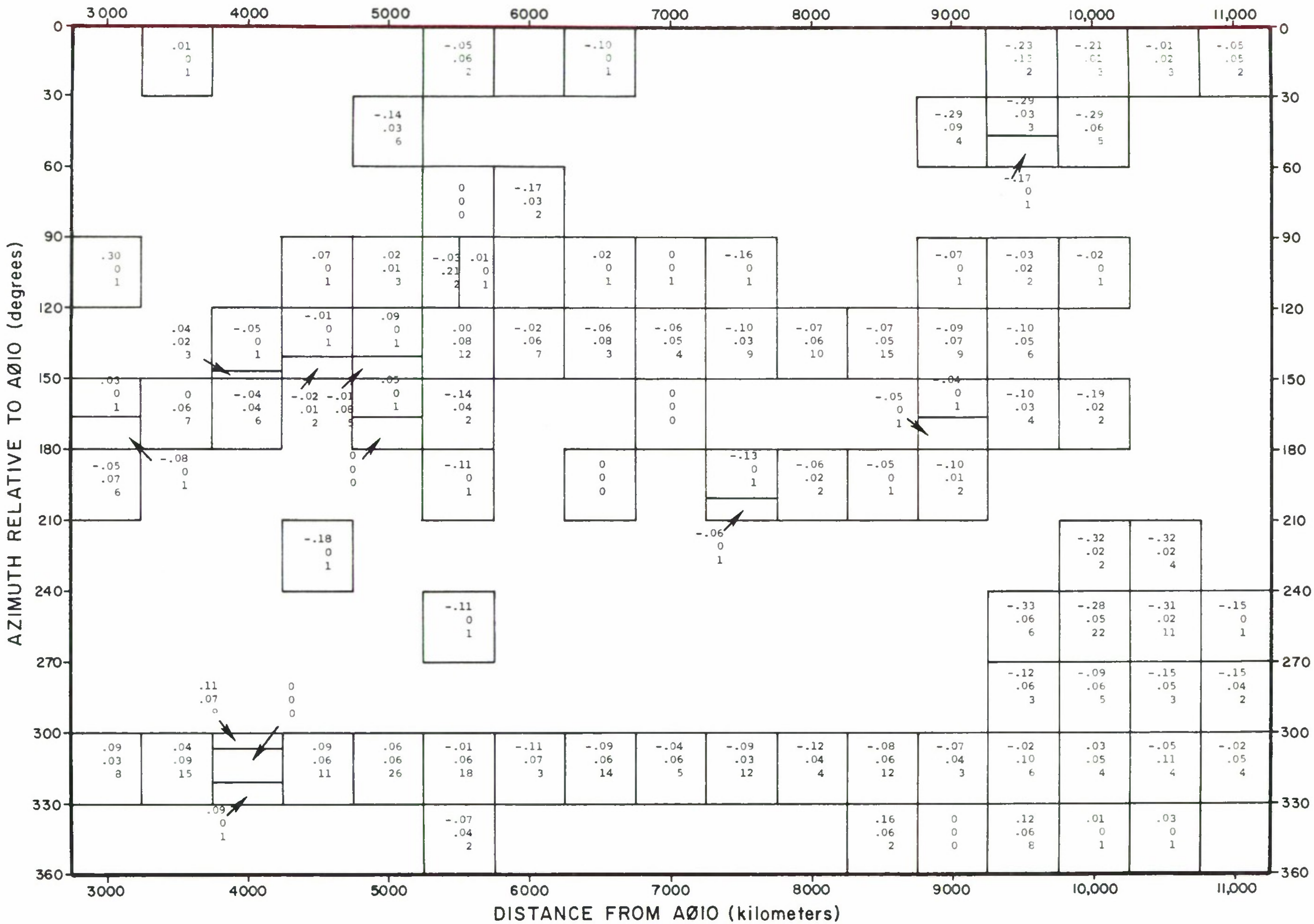


Figure 11. Subarray C2

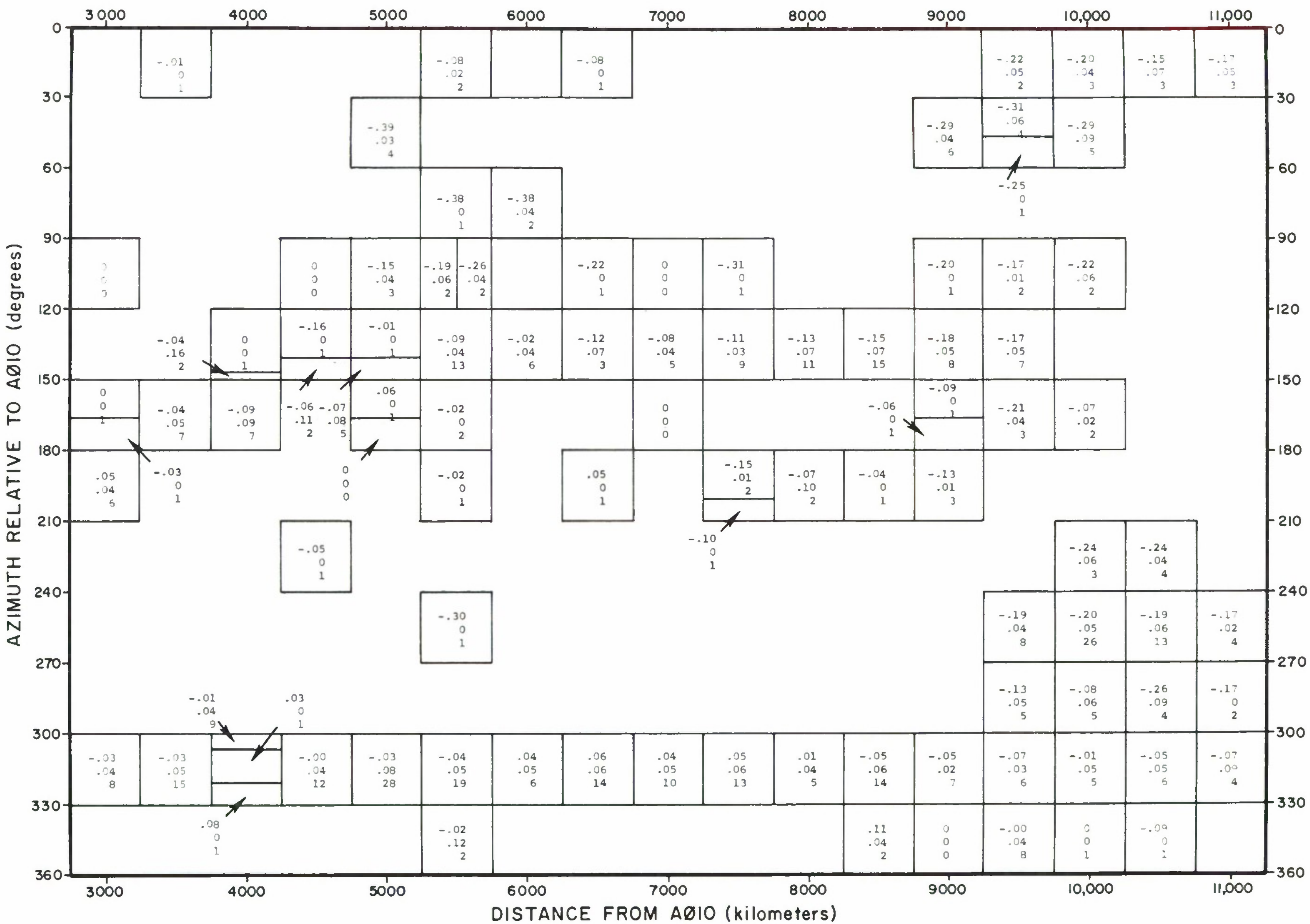


Figure 12. Subarray C3

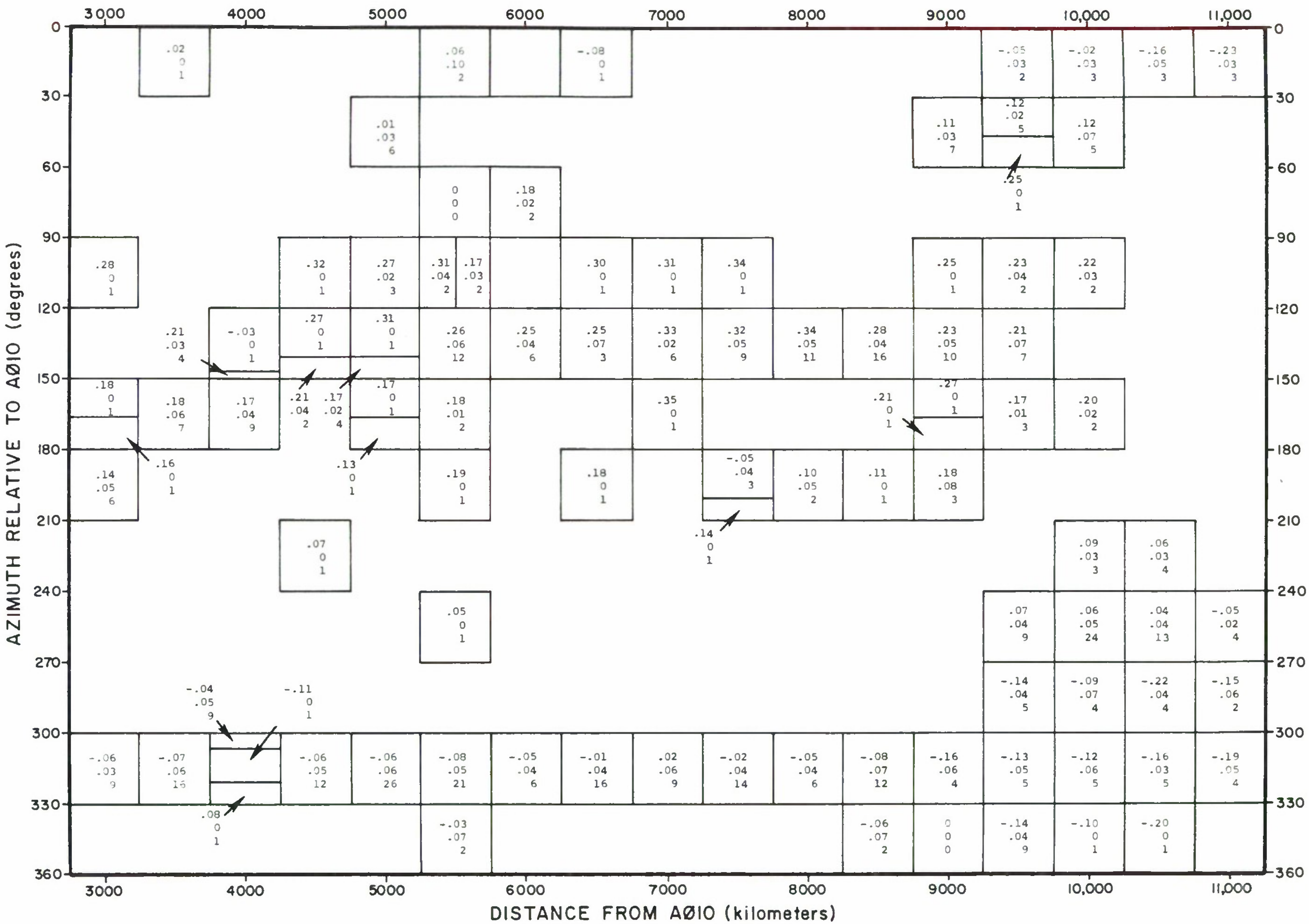


Figure 13. Subarray C4

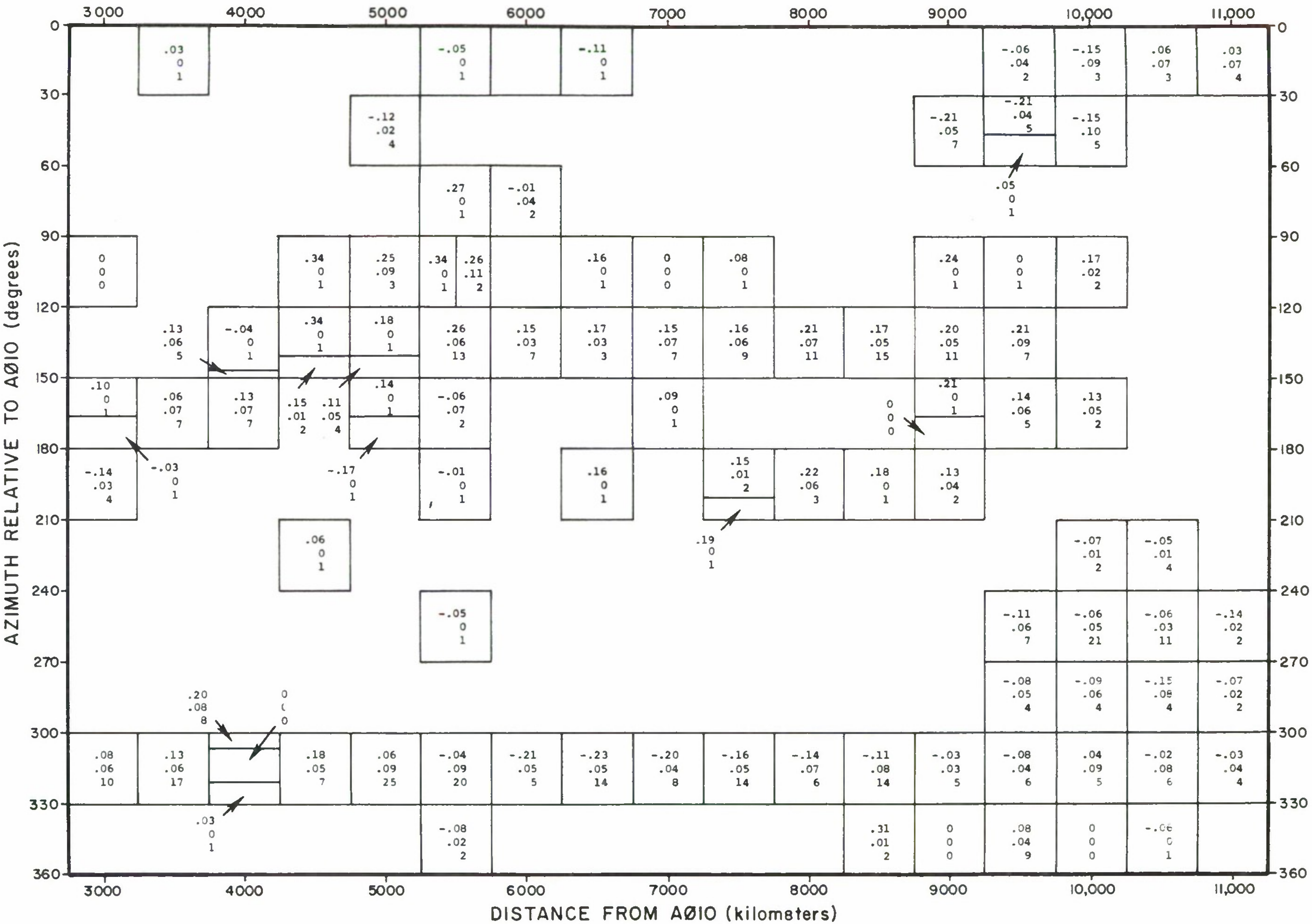


Figure 14. Subarray D1

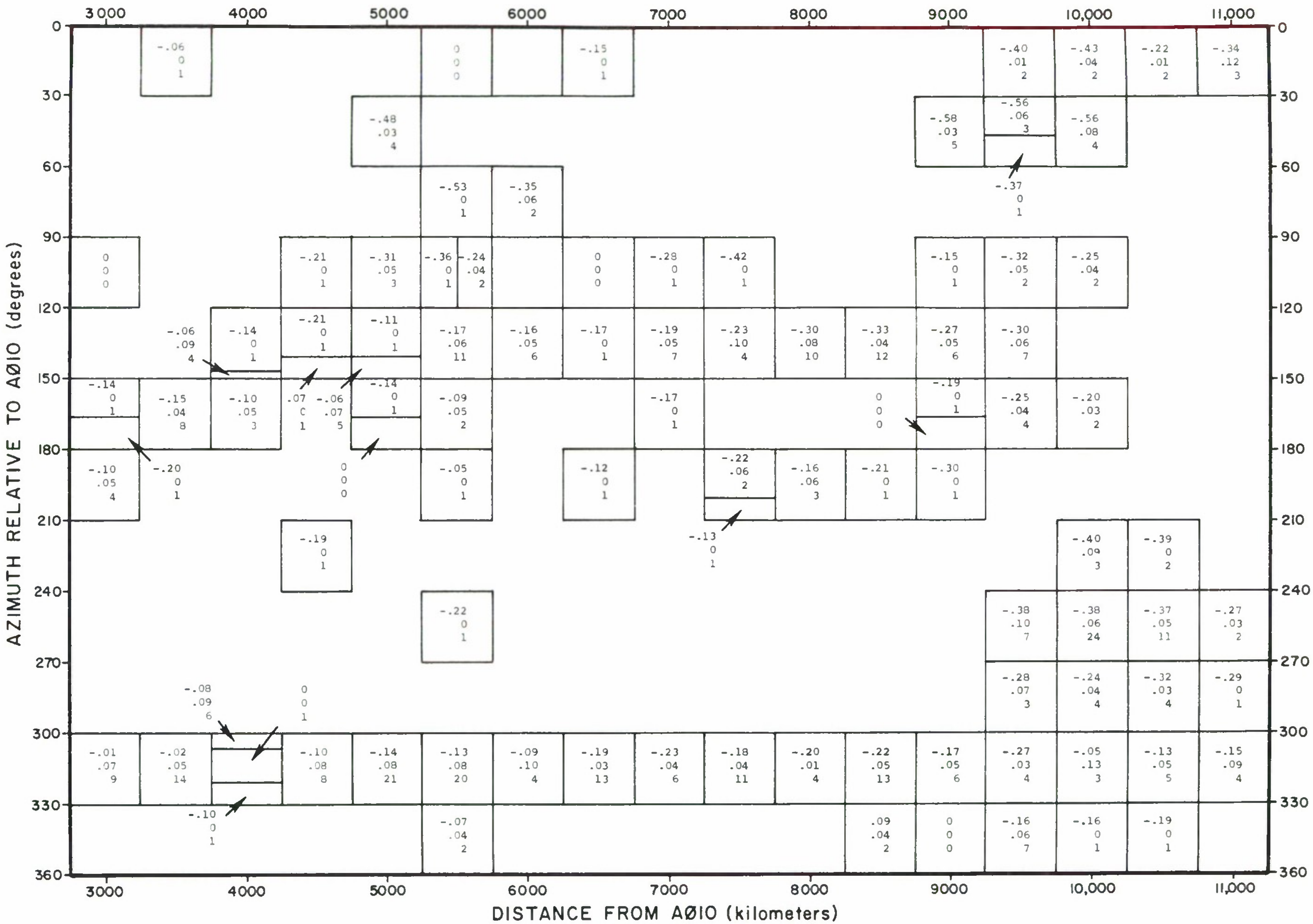


Figure 15. Subarray D2

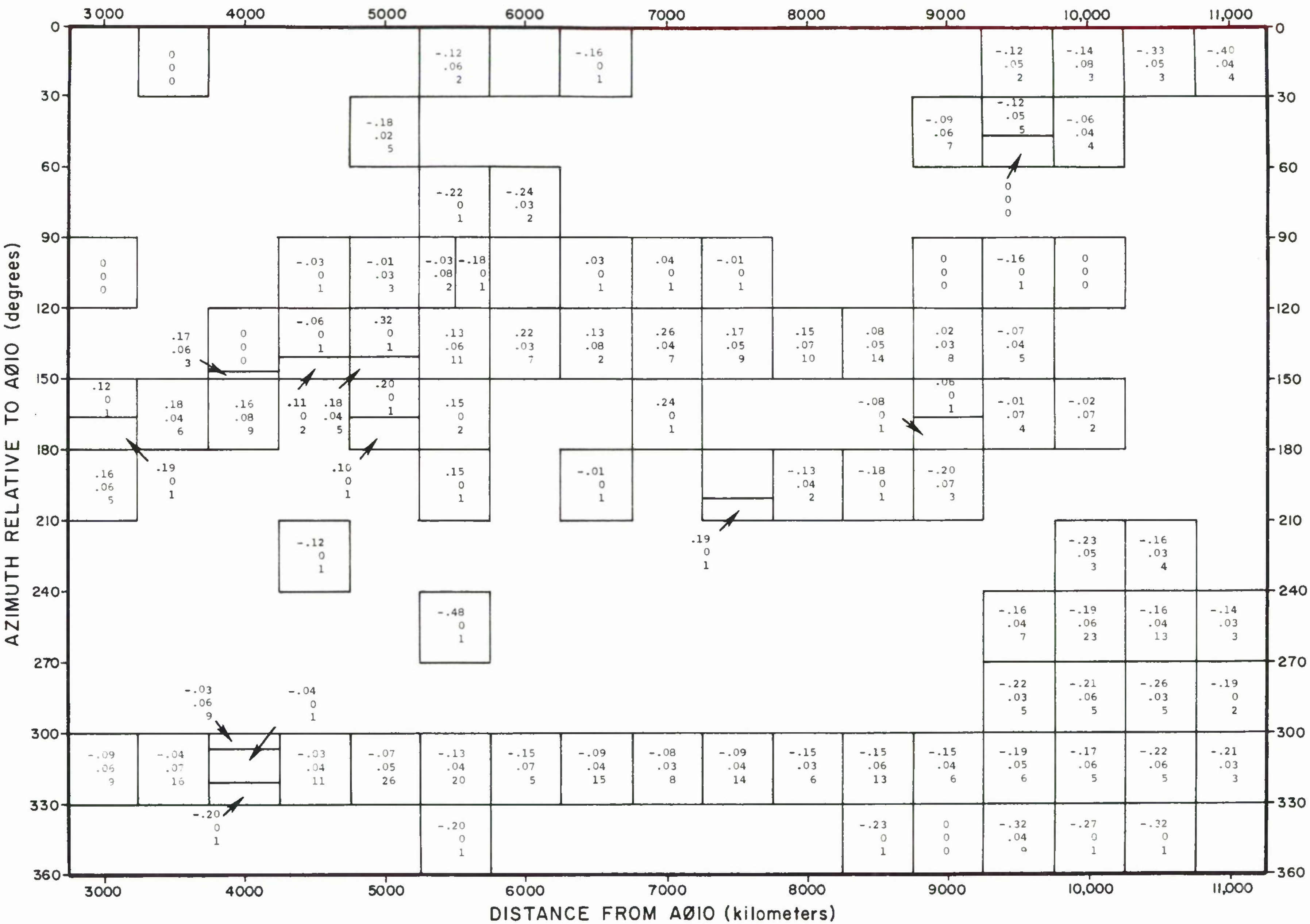


Figure 16. Subarray D3

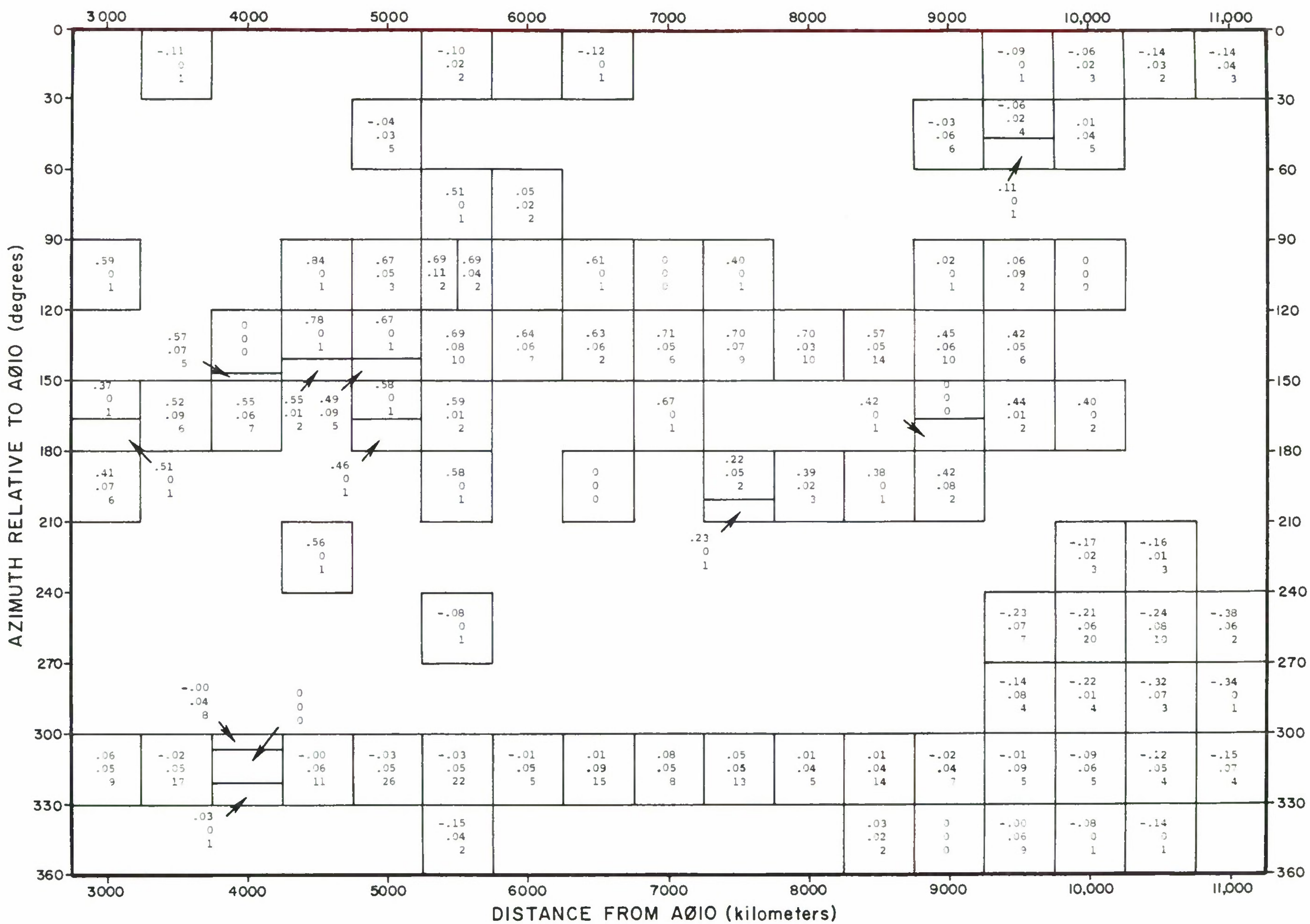


Figure 17. Subarray D4

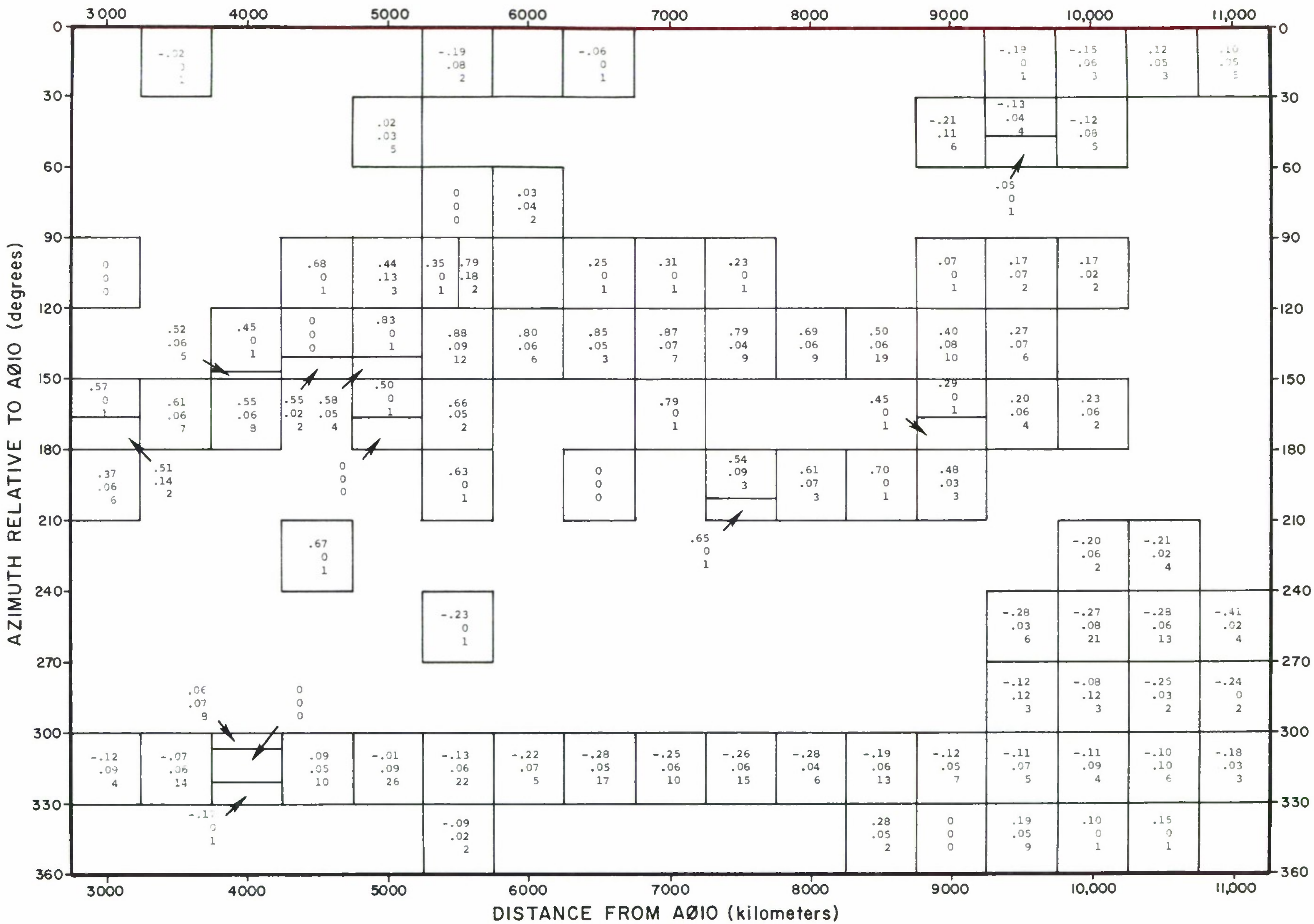


Figure 18. Subarray E1

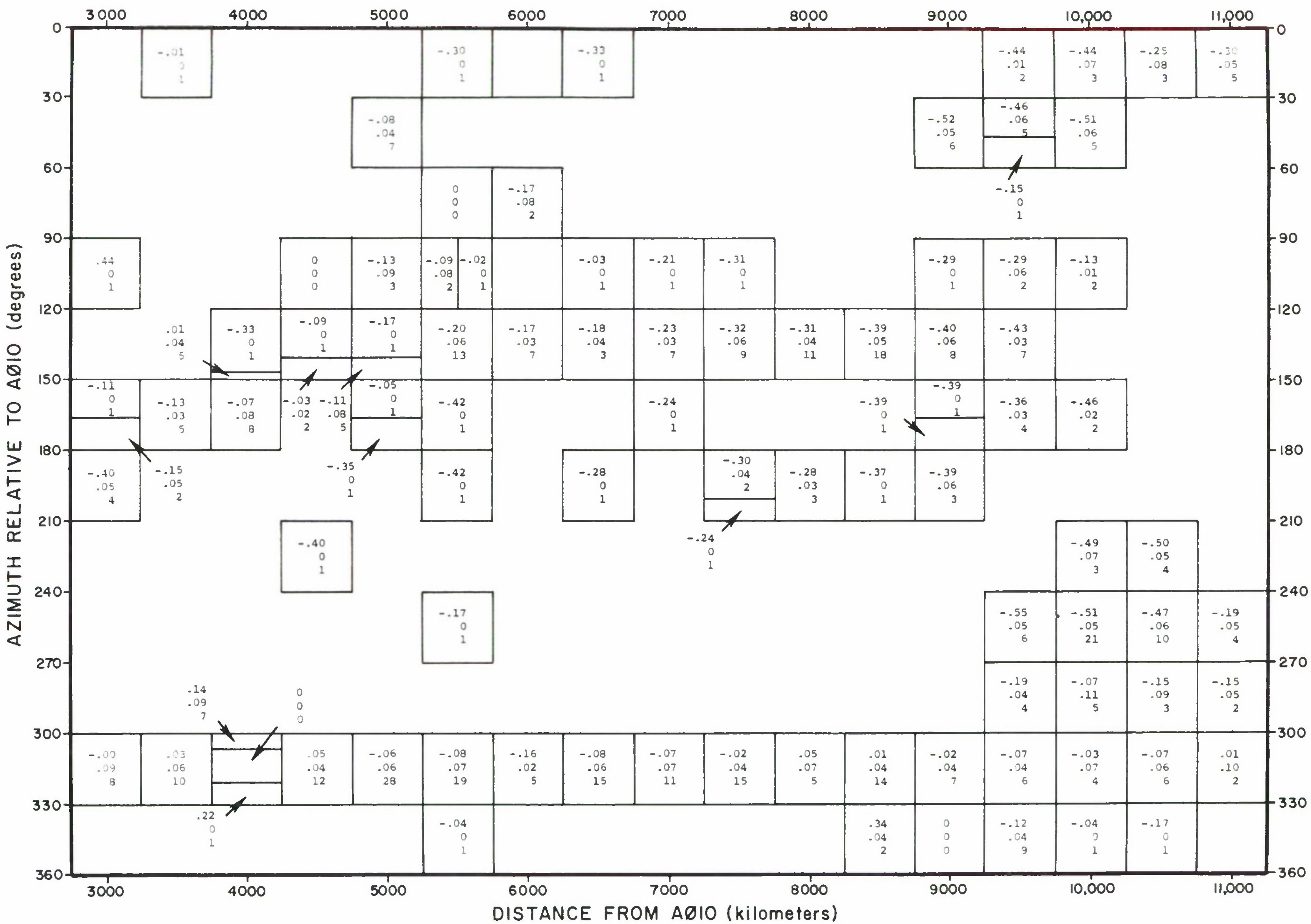


Figure 19. Subarray E2

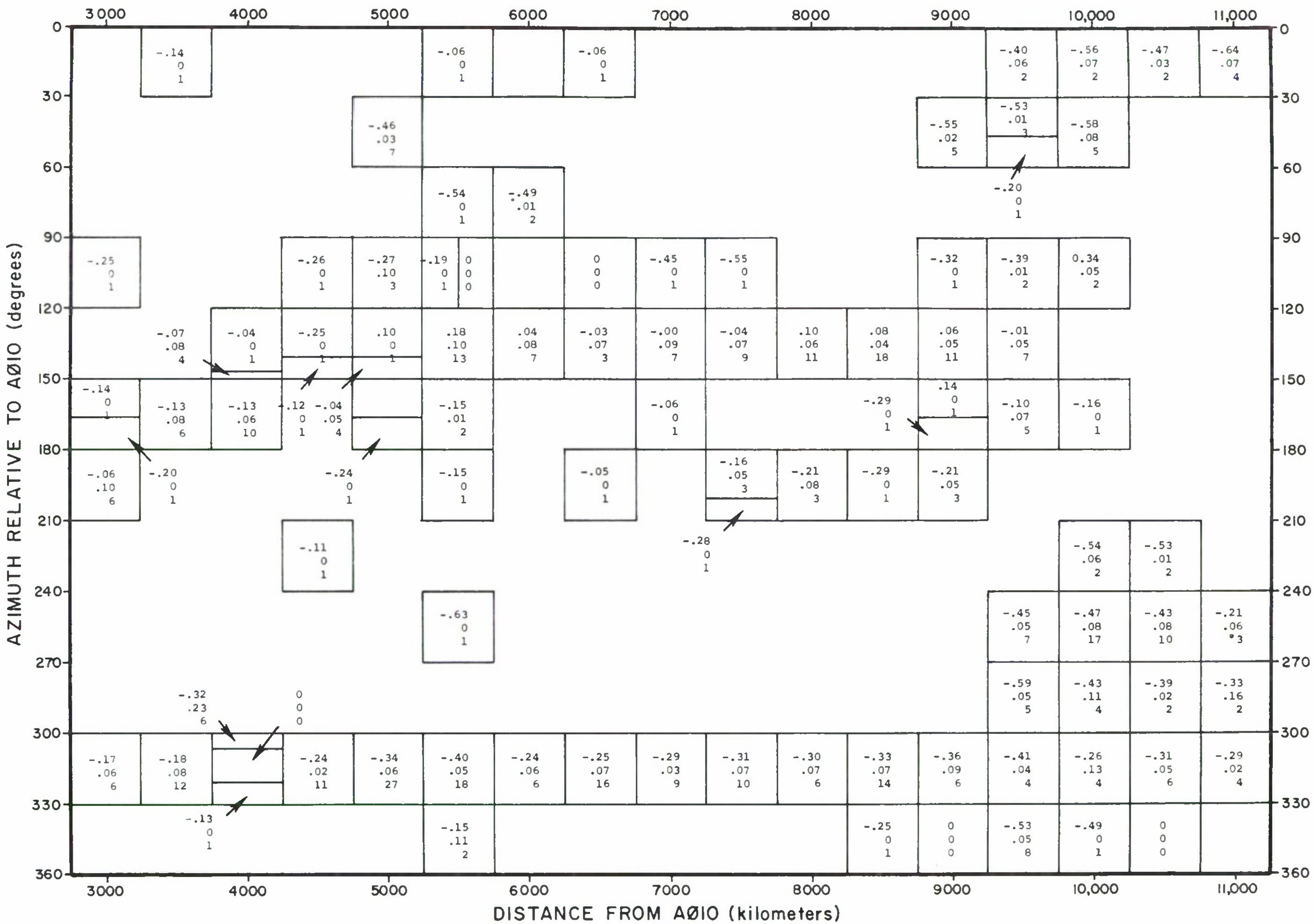


Figure 20. Subarray E3

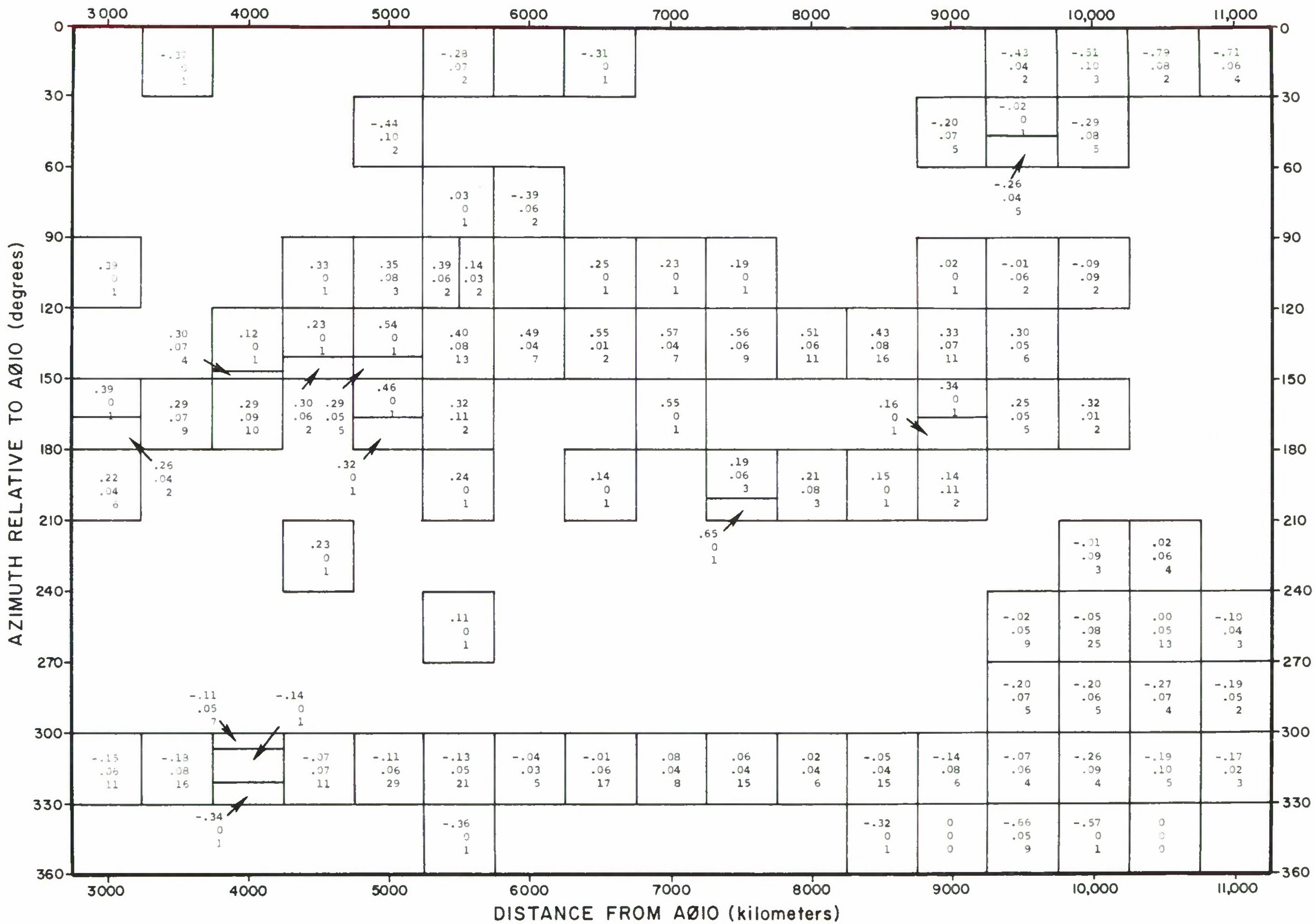


Figure 21. Subarray E4

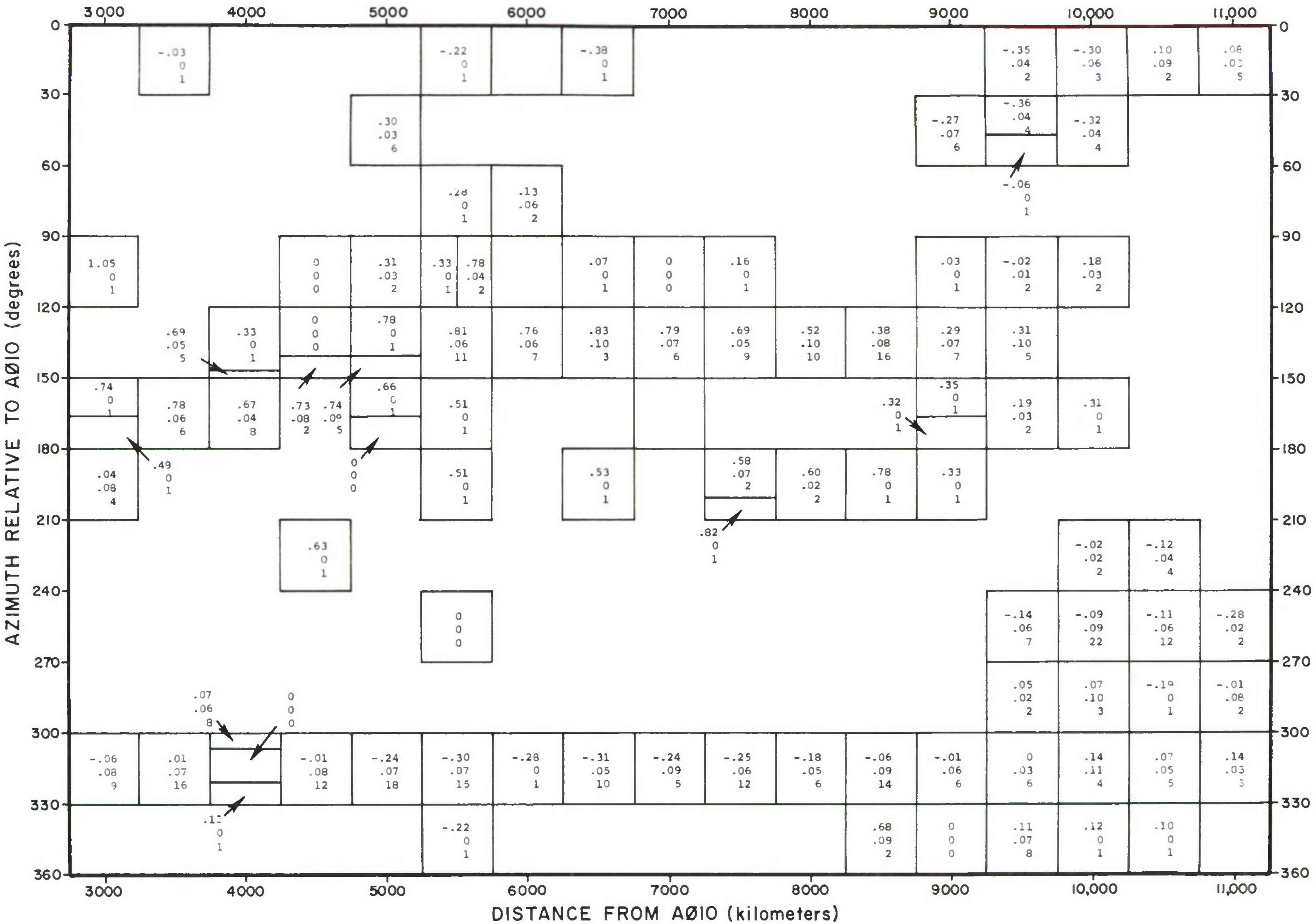


Figure 22. Subarray F1

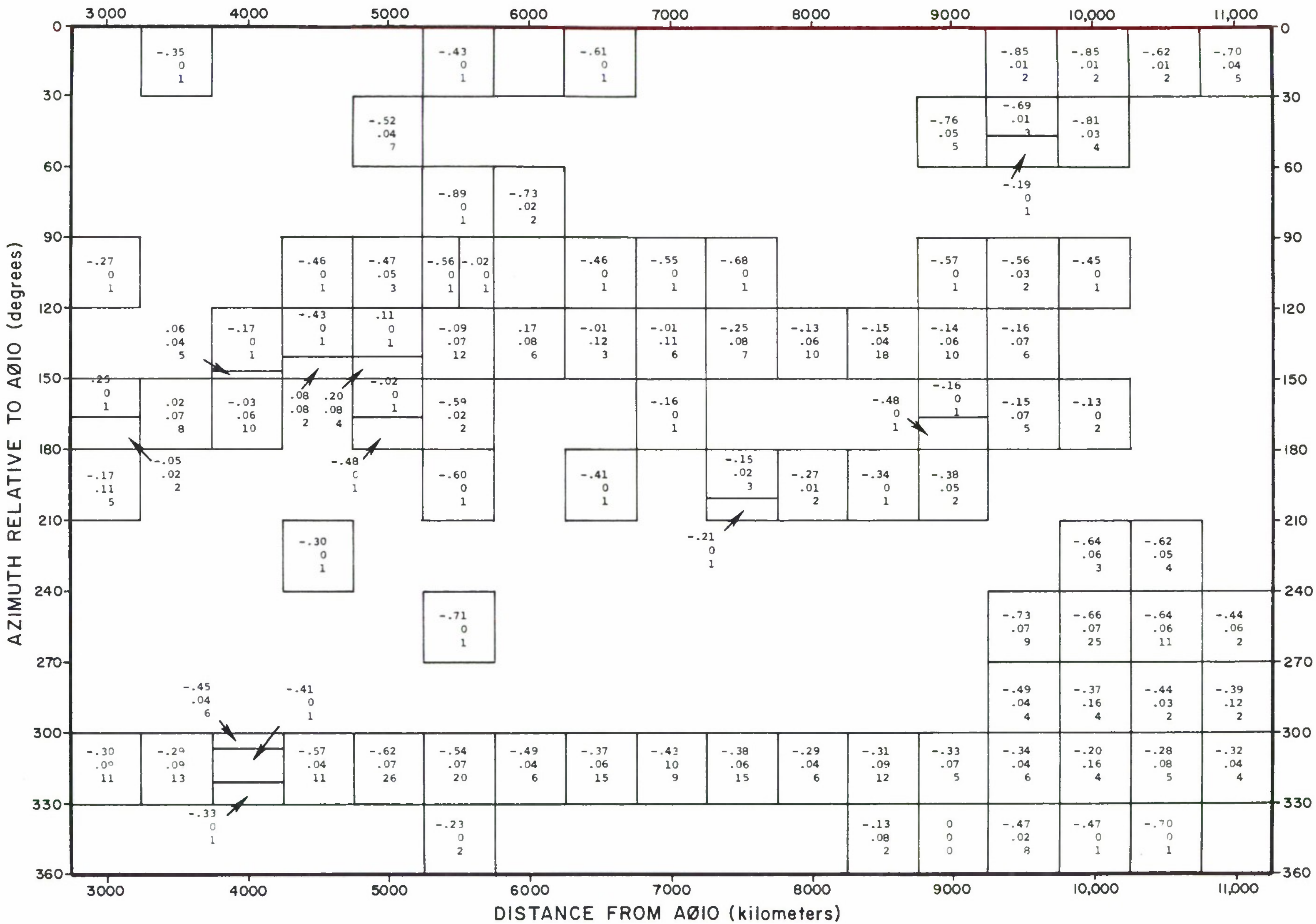


Figure 23. Subarray F2

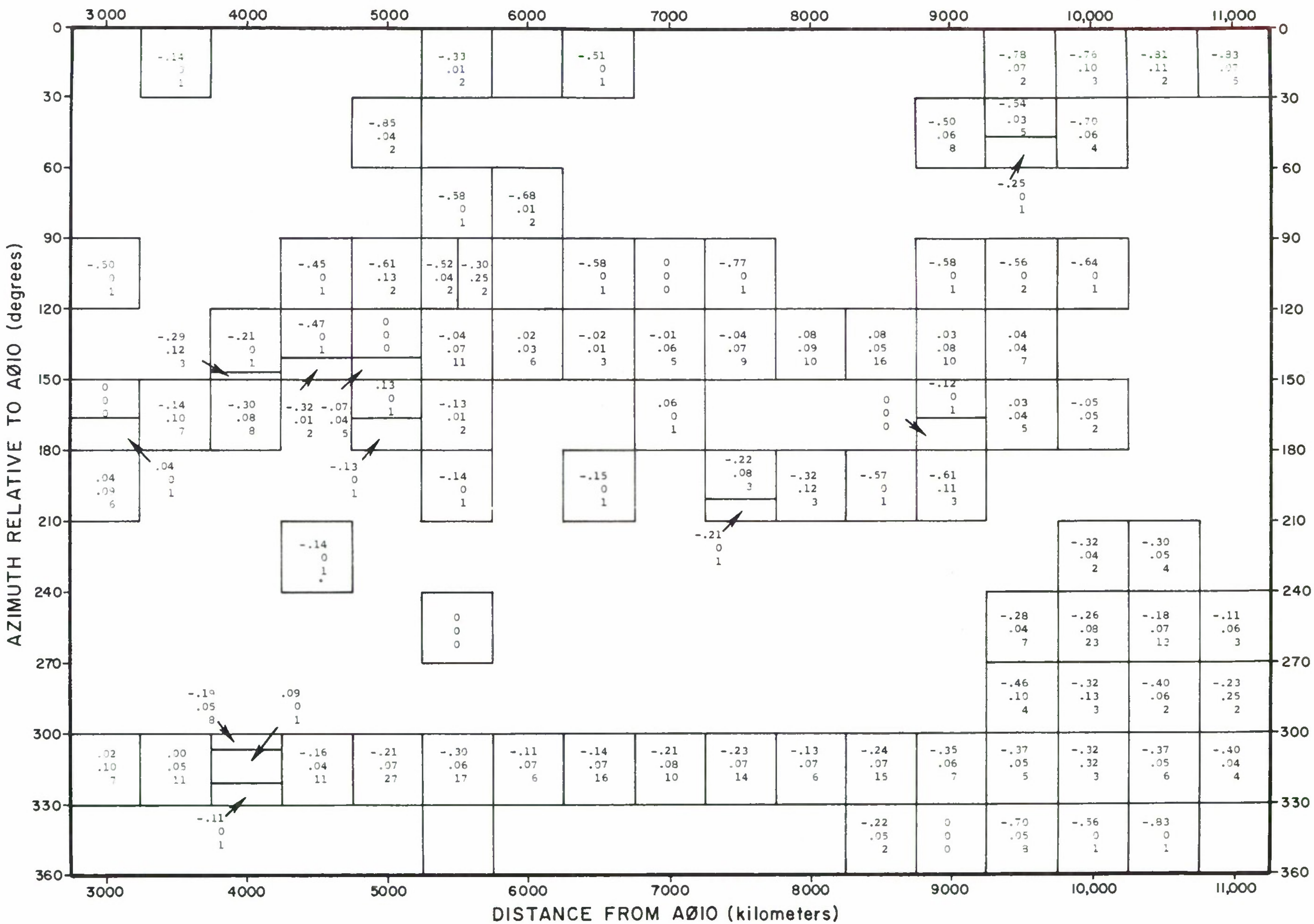


Figure 24. Subarray F3

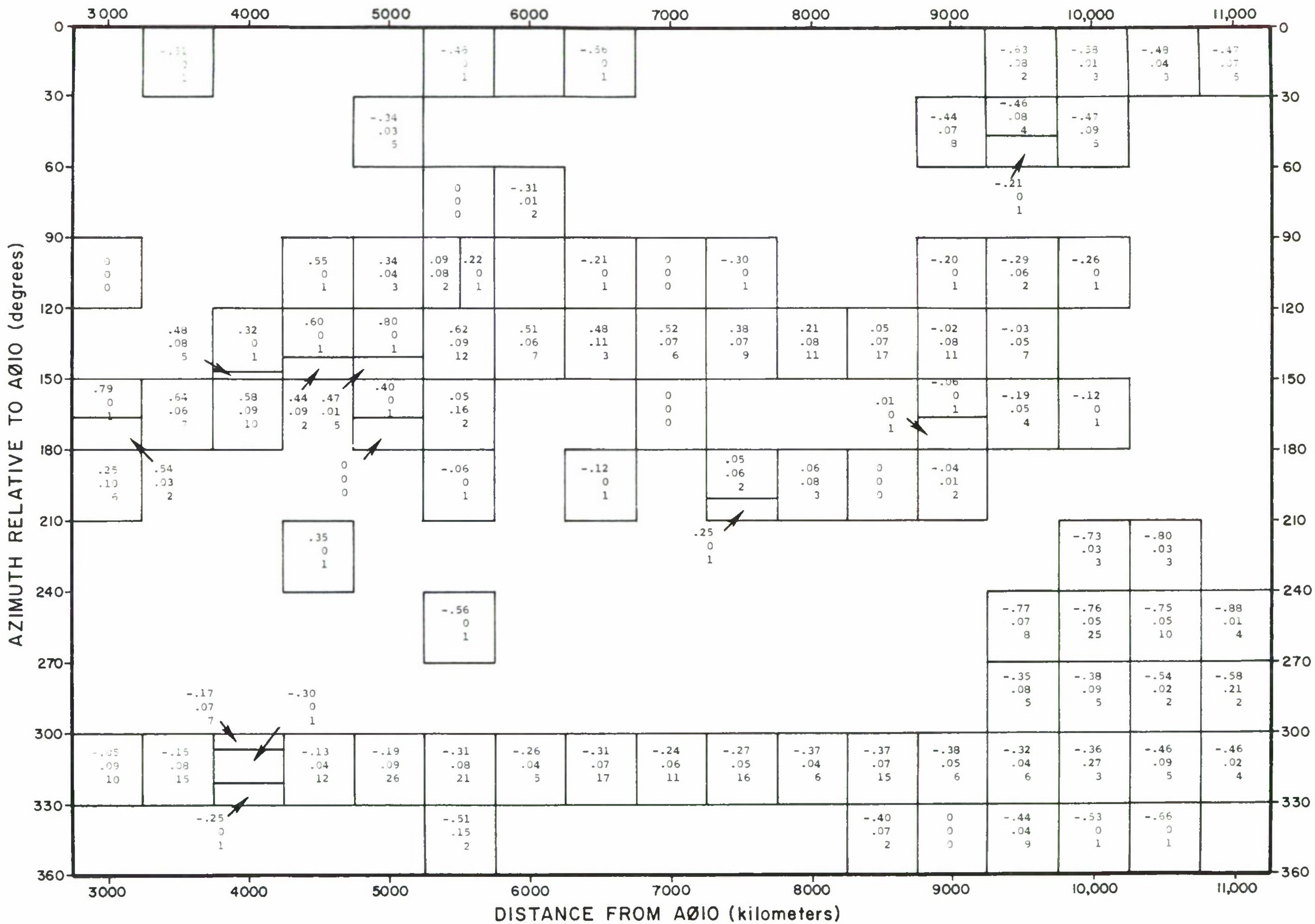


Figure 25. Subarray F4

APPENDIX A

SEISMIC DATA LABORATORY
ALEXANDRIA, VIRGINIA

DIGITAL COMPUTING SECTION

A. IDENTIFICATION

Title: ANOMALY

COOP Identification: Z108

Category: General

Programmer: Nicholas Fletcher

Date: 5 July 1967

B. PURPOSE

To compute travel-time and amplitude anomalies

C. USAGE

1. Operational Procedure: This is a FORTRAN 63 program. All input is from punched cards and the output is from the printer, and an off-line card image tape.
2. Parameters: Input parameters consist of the latitude and longitude of the location of the subarray centers.
3. Space Required: Not Applicable
4. Temporary Storage Requirements: None
5. Alarms: None
6. Error Codes: None
7. Error Stops: None
8. Input and Output Tape Mounting: There is no input tape. The output tape is on logical Unit 16.
9. Input and Output Formats:

The input card formats are as follows:

Subarray locations deck, must be the first deck of cards read by the program. The first card of this deck must contain the number of subarray location cards. This number is punched in Columns 1 through 5 <u>right</u> justified. The first card is followed by the subarray location cards, with one location per card. The program is limited to a maximum of 51 subarrays. 1 (One) punched in Column 10, prints out J. B. Table and station locations.

<u>Subarray location card format is as follows</u>:

FORMAT (A8, 2 (F5.0, F3.0, F5.1, A1)

<u>COLS.</u>

1-8	Subarray name, left justified
9-13	Subarray latitude degrees
14-16	Subarray latitude minutes
17-21	Subarray latitude seconds (with decimal point punched)
22	N or S for north or south latitude
23-27	Subarray longitude degrees
28-30	Subarray longitude minutes
31-35	Subarray longitude seconds (with decimal point punched)
36	E or W for east or west longitude

The location cards are followed by the first event card ----

<u>Event card format is as follows</u>:

Columns 1 through 14 contain the origin time of the event.

<u>COLS.</u>

1-2	Month
3-4	Day

COLS.

5-6	Year
7-8	Hour
9-10	Minute
11-14	Second to the nearest tenth of a second
15-18	Latitude of the event in degrees to the nearest tenth
19	N or S for North or South
20-24	Longitude of the event in degrees to the nearest tenth
25	E or W for East or West longitude
26-28	Depth of event to the nearest kilometer
29-31	Magnitude to the nearest tenth
32-36	This is an output field. The program will compute the distance (to the nearest kilometer) between the event and the standard subarray (AO for LASA)
37-39	This is an output field. The program will compute the station to epicenter azimuth (to the nearest degree relative to AO)
40-78	Not used by the program, but reproduced on output.
79-80	Must be blank, to identify this card as an event card and not a phase card.

Each event card should be followed by phase cards. A phase card contains the observed phase data for a given subarray. Each phase card must have an index number punched in Columns 79-80. This index is established by the order of the subarray location cards (see Sec-C9). There does not have to be a phase card for every subarray location card nor a specific numerical order.

Phase Card Format:

FORMAT (Columns 1 through 9 contain the phase arrival time at this subarray)

COLS.

1-2	Hour
3-4	Minute
5-9	Second to the nearest hundredth
10	Not used
11-14	Amplitude (zero to peak) to the nearest millimicron
15-16	Not used
17-20	Amplitude (peak to peak) to the nearest millimicron
21	Not used
30	Signal Quality
31-35	Time anomaly to the nearest hundredth of a second -- this is an output item computed by the program.
36-40	Amplitude anomaly zero to peak relative to geometric mean computed by the program (output field)
41-42	Subarray name code (output item)
43	Not used
44-45	Reference subarray (for each event) (only in last phase card)
46-50	Peak to peak amplitude anomaly relative to geometric mean (output field)
51-55	Zero to peak amplitude anomaly normalized to average amplitude (O-P) (output field)
56-60	Peak to peak amplitude anomaly normalized to average amplitude (P-P) (output field)
61-78	Reserved but not used by program
79-80	Index number of subarray recording this phase must correspond to subarray location card.

Additional events with their associated phase cards follow in like fashion for as many events not repeated in the deck setup.

The output tape is a card image tape, with the same information and format as the input tape with the addition of the computed values for distance and azimuth for event cards, and travel-time and amplitude anomalies for the phase cards.

10. Selective Jump and Stop Settings: None

11. Timing: Approximately 3.5 seconds per event

12. Accuracy: No better than the input data

13. Cautions to User: Every phase card must have an index number. If Columns 79-80 are blank, the program assumes it is an event card.

14. Equipment Configuration: Standard F-63 COOP monitor system with the card reader on Unit 7 and the printer on Unit 6 and the output tape on Unit 16.

15. References: Letter from MIT dated April 8, 1966

D. METHOD

Definitions

Observed Travel-Time = Observed Phase Arrival Time Minus Event Origin Time

Predicted Travel-Time = Travel-Time for the J-B Table. Found by table look-up on distance and depth with four-point interpolation for distance and linear interpolation for depth.

O_i = Observed travel-time at subarray i

H_i = Predicted travel-time to subarray i

O_r = Observed travel-time at standard subarray

H_r = Predicted travel-time to standard subarray

Transit Time Residual (Travel-Time Anomaly) = $O_i - O_r + H_r - H_i$

(Relative) Amplitude Anomaly = Amplitude (Zero to Peak) at subarray i divided by geometric mean amplitude (zero to peak)

(Average) Amplitude Anomaly = Amplitude (Zero to Peak) at subarray i divided by arithmetic average amplitude (zero to peak) for all functioning subarrays.

Relative and average amplitude anomalies are also computed in like manner for the peak to peak measurements.

APPENDIX B

SEISMIC DATA LABORATORY
ALEXANDRIA, VIRGINIA

DIGITAL COMPUTING SECTION

A. IDENTIFICATION

Title: Display and Analysis of Anomalies

COOP Identification: Z95 DISPLAY

Category: General

Programmer: J. W. Monroe

Date: 19 July 1966

B. PURPOSE

To take the output from the anomaly program and compute the average, standard, deviation, and number of occurences of a selected anomaly for selected subarrays of sensors, distances, and azimuths.

C. USAGE

1. Operational Procedure: This FORTRAN-63 program is with a binary or symbolic deck and a set of control cards for each use.

2. Parameters: None

3. Space Required: 21,222 buffers

4. Temporary Storage Requirement: None

5. Print-Outs: The program first prints out the anomaly used, followed by the distance and azimuth criteria and the sub-arrays or sensors used. If any seismograms are to be deleted from processing, they are listed next. Following this will be a page for each subarray or sensor with the average, standard deviation and number of occurrences of the selected anomaly for each distance and azimuth chosen. If plotting is requested, the last page will contain scale factors and other information pertaining to the plots.

6. Error Returns: None

7. Error Stops: None

8. Input and Output Tape Mountings:

Logical Unit #4 - Input BCD tape from ANOMALY

Logical Unit #3 - Output plot tape if desired

9. Input and Output Formats:

INPUT: (only one case per run)

Card #	Cols	Format	Description
1	1	I1	Anomaly to be used (see last page)
	5	I1	Plot switch 1-plot, blank-no plot
2	1-10	I10	Number of Dels (Max 19)
	11-20	I10	Number of Azimuths (Max 13)
	21-30	I10	Number of Subarrays or Sensors (Max 21)
next N	1-10	F10.2	Distance (km)
	11-20	F10.2	± Distance (km)

Where N = No. punched in Cols 1-10 on card #2 (Max 19)

next M	1-10	F10.2	Azimuth (Deg)
	11-20	F10.2	± Azimuth (Deg)

Where M = NO. punched in Cols 11-20 on card #2 (Max 13)

next L	1-10	F10.0	Subarray or Sensor Number

Where L = NO. punched in Cols 21-30 on card #2 (Max 21)

next D	1-4	I4	Seismogram Nos. to be deleted (Max 100)

OUTPUT: The printed output will be that described in PRINT-OUTS. The plot tape on logical unit #3 will contain a plot for each subarray or sensor of the average for that subarray minus the average of averages for all subarrays. The plotted value will be computed for each distance at each azimuth (in that order) until N points have been plotted where N equals the number of dels times the number of azimuths. The plots will always represent a new del every tenth of an inch.

10. <u>Selective Jump and Stop Settings</u>: None

11. <u>Timing</u>: 2 mili-sec per case where each case has a separate distance, azimuth, subarray, and anomaly.

12. <u>Accuracy</u>: The same as input data

13. <u>Cautions to Users</u>: Both logical units 3 and 4 must be mentioned in the COOP card. If no plot is desired, use the BY3 convention. The plot routine is not internally controlled so the user must request the same number of files to be plotted as there are subarrays or sensors with a maximum of ten across the plot. Observe that there are maximum limits on the number of distance and azimuth intervals and number of subarrays and seismograms to be deleted.

14. <u>Equipment Configuration</u>: Standard COOP for FORTRAN-63

15. References:

    Program write-up for <u>ANOMALY</u> Fletcher - 16 June 1966

D. <u>METHOD</u>

$$\text{Average} = \bar{X}_{i,j,k} = \frac{1}{N_{i,j}} \sum X_{i,j,k}$$

$$\text{Standard Deviation} = \sigma_{i,j,k} = \frac{\left[\sum X^2_{i,j,k} - \left(\sum X_{i,j,k} \right)^2 / N_{i,j} \right]}{N_{i,j} - 1}$$

$$\text{Number of Occurrences} = N_{i,j,k}$$

where, i = azimuth $\pm$ deg's.

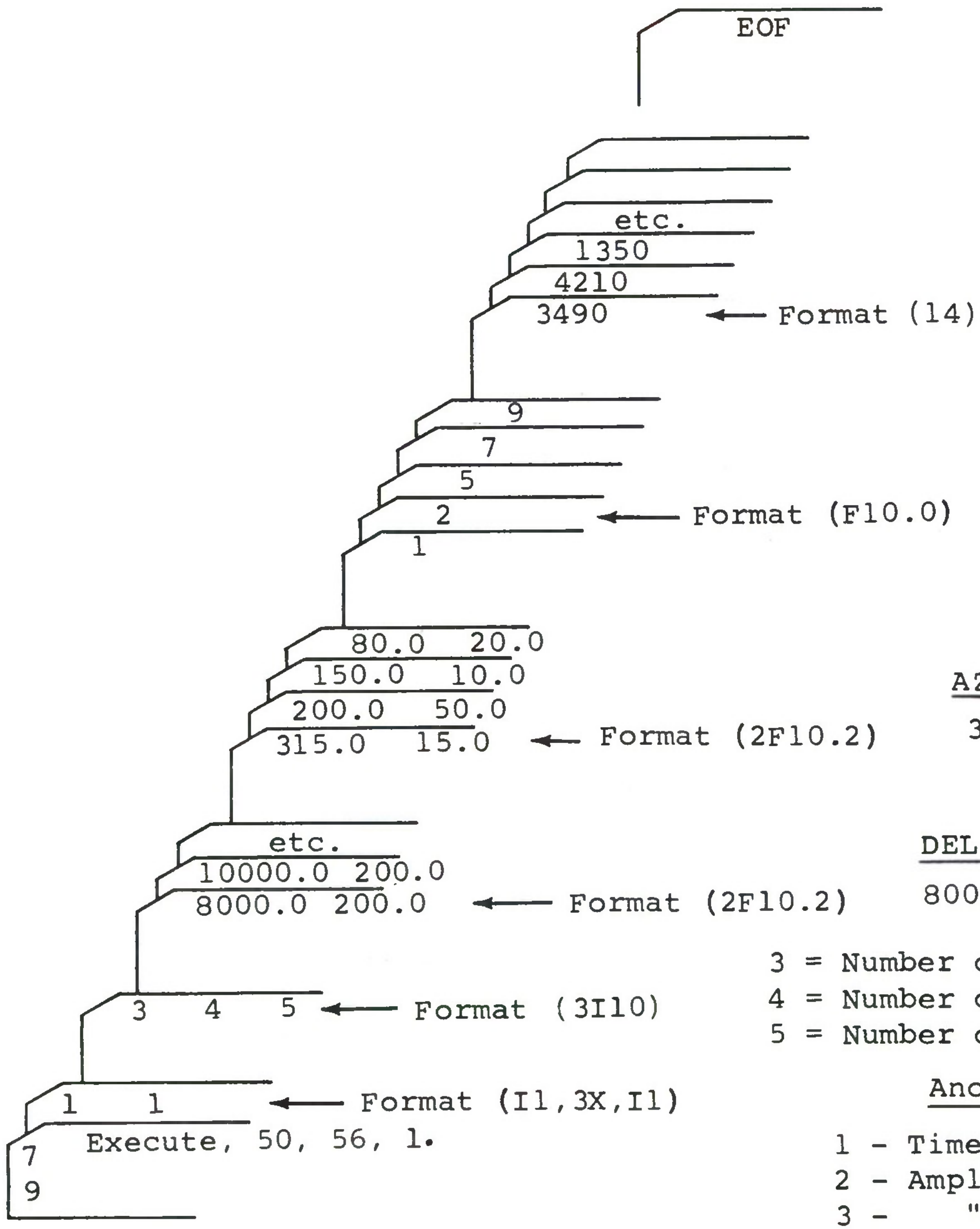
j = distance $\pm$ km's

k = subarray or sensor

N = number events pertinent to the specified coordinates and specified subarray

$X_{i,j,k}$ = anomaly used

SAMPLE INPUT DATA FOR DISPLAY



Event nos. punched on cards (1 per card) shall not be processed Max (100)

Subarray No.

AZI Intervals

315 ± 15 Deg

DEL Intervals

8000 ± 200 km

3 = Number of Del Intervals - Max(19)
4 = Number of Azi Intervals - Max(13)
5 = Number of Subarrays or Sensors - Max(21)

Anomaly To Be Used

1 - Time
2 - Amplitude (Z - P) Relative
3 - " (P - P) "
4 - " (Z - P) Average
5 - " (P - P) "

Plot Switch (col no. 5)

blank - no plot
1 - plot desired

M E M O R A N D U M

TO: Users of Program DISPLAY

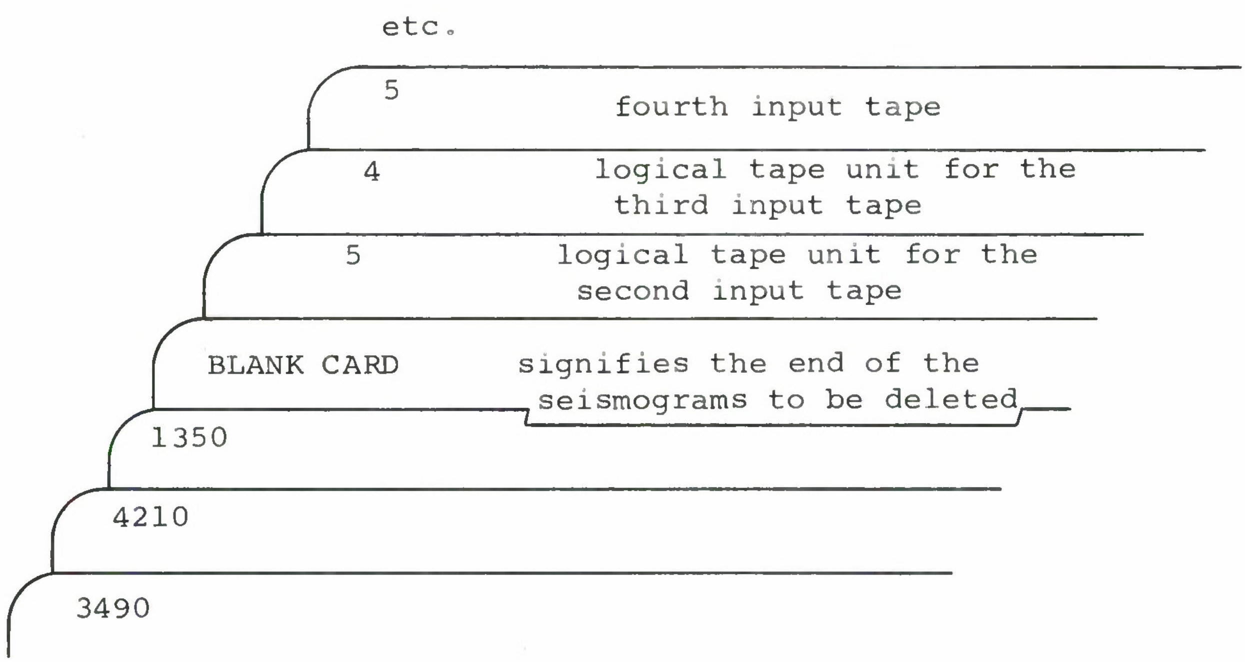
FROM: J. W. Monroe

DATE: 2 September 1966

SUBJECT: Additional Features of Program DISPLAY

REFERENCE: Z95 DISPLAY Program Writeup, 19 July 1966

The user may now run DISPLAY using more than one input tape described in the program writeup referenced above. The first input tape <u>must</u> be on Logical Unit 4 but the second, third, etc., tapes may be assigned to any logical unit from 1 thru 49 inclusive, except Logical Unit 3 (the plot tape). When using more than one input tape, Logical Units 3,4, and all other logical units must be mentioned in the COOP card. The control card setup for the case of more than one input tape is exactly the same as that shown in the SAMPLE INPUT DATA FOR <u>DISPLAY</u> of the writeup, except that following the last card of seismograms to be deleted or following the last subarray number if there are no deletion cards, a blank card must be inserted followed by the logical tape assignment for the <u>second</u> input tape. If more than two input tapes are used, additional cards are used to specify the logical tape unit for input tapes 3,4, etc., but the blank card is not used again. Format for these tape assignments is I5. The following is a sample card setup starting with the deletion cards:



As soon as an end of file is encountered on the input taps being processed, a tape assignment card is read in and the program pauses with the next input logical unit number displayed in the "A" register. When the Start Key is hit, the program begins processing the new input tape. Two input tape units might be used, such as 4 and 5, where the first tape is on Unit 4 and the second tape is mounted on 5 while 4 is being processed. After Unit 5 begins processing, another could be mounted on Unit 4.

DEBUGGING AIDS FOR DISPLAY

Jump Key 2 — On displays the event number being processed in octal in the "A" register. Program halts until Start Key is hit. For exact stops, leave JK-2 on and step through events with Start Key. Program halts on header card of event being displayed in "A" register.

Jump Key 1 — Up causes printout of accumulation that far into the program. Turn JK-1 off as soon as printout begins

Jump Key 3 — and JK-3 off as soon as printout has finished. Use this feature sparingly since some loss of accuracy occurs when sigma is set equal to zero rather than a negative number. All other times, the accumulation is reset to its original value without loss of accuracy.

Be sure both COOP card and EXECUTE card have sufficient time limits for the case being run. For a case of 324 events with 21 stations, 17 distances, and 12 azimuths, allow at least 60 minutes.

CHANGE IN FORMAT

The format of the control cards containing the numbers of seismograms to be deleted has been changed from 14 to 15.

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13. ABSTRACT

World-wide average travel-time curves are inadequate to permit optimum phasing of teleseismic signals. Phase alignment corrections in the form of station relative travel-time anomalies of LASA, based on approximately 570 events, are presented.

14. KEY WORDS

LASA
seismometers
seismic array
seismology

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